FLYING QUALITIES CRITERIA FOR SUPERAUGMENTED AIRCRAFT

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SUPERAUGMENTED AIRCRAFT

Before proceeding with a review of superaugmented aircraft activities, it would be prudent to define what we mean by superaugmented aircraft. The term is defined below. Early applications of feedback control tended to enhance the basic static and dynamic stability of aircraft in a way that was equivalent to augmenting the basic aerodynamic stability derivatives. The resulting responses were improved but conventional. As basic aircraft stability levels became weaker and the augmentation became more elaborate, aircraft began to depart significantly from classical behavior.

Certain characteristics are highly typical of superaugmented aircraft and are also indicated below.

Definition

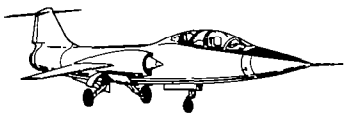
- **Aircraft with flying qualities that are dominated by the closed-loop control system rather than aerodynamic stability**

Dominant characteristics

- **Large time delays**
- **Unconventional longitudinal response**
- **Small, effective roll time constants**

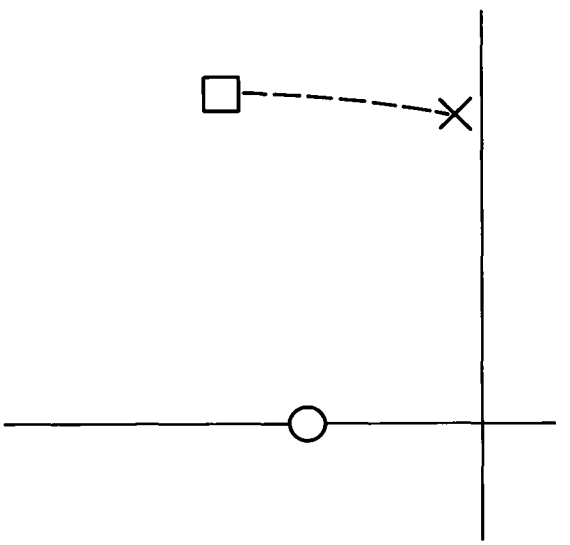
AIRCRAFT PITCH RATE POLE/ZERO CONFIGURATIONS

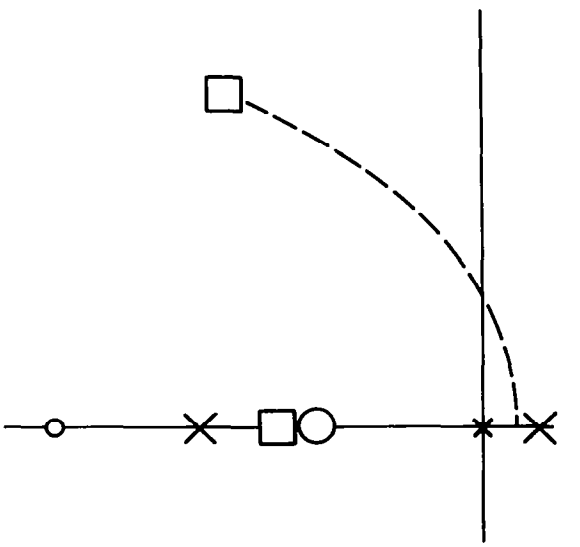
An example of a difference between a classical and superaugmented aircraft is illustrated below in terms of pitch rate transfer functions in the s plane. These diagrams are highly idealized but the basic features are quite representative. The classical aircraft typically is augmented primarily in damping so the closed-loop configuration is similar to an aircraft with good aerodynamic damping. Superaugmentation is normally required for aircraft with a basic static instability. Proportional plus integral compensation is typically used to stabilize the aircraft and provide good closed-loop frequency and damping. However, the high gains required result in the conventional attitude numerator being cancelled by a basic aircraft pole and the effective attitude lead being determined by the zero of the proportional plus integral compensation.



Classical

Superaugmented





DRYDEN SUPERAUGMENTED AIRCRAFT FLYING QUALITIES RESEARCH

Current activities of the Dryden Flight Research Facility that pertain to flying qualities of superaugmented aircraft are listed here in chronological order of their initiation. It can be seen that a variety of programs are underway. The highlights of these programs will be covered in the ensuing discussion. However, the descriptions will be brief because of the number of activities and the space available. This paper, then, will be an overview of Dryden superaugmented aircraft flying qualities research.

Program	Implementation
• F-8 DFBW Experiments	In house
• Orbiter flying qualities	In house, contractor (STI)
• Shuttle FCS improvements	In house, contractor (CALSPAN)
• Nonconventional vehicle flying qualities	Grant - Purdue
• AFTI/F-16	In house, Air Force
• Flying qualities and control system alternatives	Contractor study (STI)
• Pilot model measurements	Grant - U. Cal. Davis
• VMS Shuttle evaluation	In house, JSC
• TIFS pitch rate criteria	Contractor (CALSPAN)

F-8 DIGITAL FLY-BY-WIRE (DFBW) FLIGHT EXPERIMENTS

The F-8 DFBW was the world's first fully fly-by-wire airplane. Initial program emphasis was on system reliability and redundancy management. In recent years, the vehicle has been used to investigate flying qualities associated with advanced control laws and superaugmentation, as listed below. The time delay studies investigated the effect of transport delay on flying qualities in landing, formation flying, and in-flight refueling. Highly augmented aircraft typically have large values of equivalent transport delay. The nonlinear control law investigation was a cooperative program with the British and studied control laws that varied prefilter time constants as a function of feedback error and changed loop structure as a function of task. The PIO suppression filters study (ref. 4) was an extension of concepts developed for the Space Shuttle.

- **Time delays**
- **Nonlinear control laws (CADRE)**
- **PIO suppression filters**

OEX ORBITER FLYING QUALITIES EXPERIMENT

This effort is under the sponsorship of the Orbiter Experiments Program (OEX). The purpose is to use Shuttle data and flight experience to develop flying qualities criteria for next generation Shuttlecraft and to improve existing Shuttles where feasible. The Shuttle has some unique characteristics and mission tasks; nevertheless, it is a superaugmented vehicle, and there is much technology transfer between it and high-performance aircraft.

- **Generate flight data base for criteria for current and future Space Shuttlecraft**
- **Establish flying qualities data "pipeline"**
- **Use flight data to validate analytic/simulator studies**

DRYDEN GRANT ACTIVITIES

Grants under the direction of Dryden that pertain to superaugmented aircraft are outlined below.

The investigator for the Purdue grant is Dr. Dave Schmidt. The integrated pilot-optimal control synthesis simultaneously utilizes an optimal control pilot model and modern control theory to produce control system designs with optimum flying qualities. The optimal control approach to the Neal/Smith flying qualities criteria uses an optimal control pilot model instead of the classical pilot compensation model. The pilot parameter identification techniques study is looking at the use of time series analysis to measure pilot dynamics, strategy, and workload from flight-test time histories.

Principal investigator for the University of California-Davis grant is Dr. Ron Hess. This effort is aimed at using existing pilot measurement techniques to obtain data from ongoing flight experiments and obtain a flight-validated data base of pilot math model parameters. Both classical and optimal control models will be used.

Purdue University: (Schmidt)

Develop prediction techniques for flying qualities of complex, nonconventional vehicles

- **Integrated pilot-optimal control synthesis**
- **Optimal control approach to Neal/Smith**
- **Pilot parameter identification techniques**

University of California - Davis (Hess)

Establish flight-validated pilot model data base

- **Analyze F-8 DFBW flight experiments**

AFTI/F-16 FLYING QUALITIES FLIGHT EXPERIENCE

The AFTI/F-16 is a superaugmented aircraft with direct lift and side force control and a task-tailored multimode flight control system. It is a very ambitious program that is striving to evaluate highly advanced control system mechanizations and architectures as well as unconventional control laws. Initial program emphasis has been on checkout of the digital flight control system and functional evaluation of the flight control concepts. Much qualitative flying qualities information has been obtained, and the highlights of this experience are indicated below.

- **Utility of task-tailored flying qualities demonstrated**
- **Technology not available to optimize control modes**
- **PIO and roll ratchet tendencies persist**

AMES VMS SHUTTLE FLIGHT CONTROL IMPROVEMENT STUDY

The Ames Vertical Motion Simulator (VMS) was used in a recent program to study Shuttle flying qualities in approach and landing. This program was sponsored by the Johnson Space Center. Dryden participated because of its background in previous Shuttle approach and landing studies. The program is outlined below.

Objectives

Evaluate proposed changes to Shuttle FCS to improve flying qualities in approach and landing

Configurations

- **Baseline Shuttle**
- **Shaped pitch rate**
- **Lead/lag prefilter**
- **Slapdown system**
- **Rate command/att hold**
- **Sink rate command**
- **C***

Results

- **Shaped pitch rate, slapdown, and C* best of mods**
- **Slapdown and C* eliminated after aggravated maneuvers due to rate limiting**
- **Pilots with extensive Shuttle training preferred baseline system**
- **Test pilots without Shuttle training preferred shaped pitch rate**

TIFS PITCH RATE CRITERIA FLIGHT RESEARCH PROGRAM

The Air Force/Calspan Total In-Flight Simulator (TIFS) very recently completed a program under joint Dryden/Langley sponsorship to investigate flying qualities criteria for pitch rate command systems. The objectives of the program and configurations tested are outlined below. Preliminary results indicate that superaugmented configurations were rated level two or three. Prefilters that tended to restore more classical aircraft response improved the ratings.

Objectives

- Generate flight data base for improved pitch rate command systems
- Emphasis on superaugmented aircraft

Configurations

- 200,000 lb class advanced aircraft
- Negative static stability
- Neutral static stability
- Proportional + integral augmentation
- With/without prefilters
- Pitch rate augmentation

SUMMARY

This review can be summarized as follows.

- **Additional data needed to develop superaugmented aircraft flying qualities criteria**
- **Dryden activities aimed at increased understanding of superaugmentation and providing flight-validated data base**
- **Current effort involves F-8 DFBW, Space Shuttle, AFTI/F-16 and X-29**

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