A BRIEF REVIEW OF AIRCRAFT CONTROLS RESEARCH OPPORTUNITIES IN THE GENERAL AVIATION FIELD

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CONTROLS TECHNOLOGY REVIEW

The review process itself is part of a feedback control system (Figure 1). The work already accomplished by NASA on flight test programs (Block A) and on trade studies (Block B) must be reviewed to determine the potential controls technology benefits available to the general aviation industry (Block C). General aviation industry constraints (Block D) must be defined and applied to determine the currently useable controls technology (Block E). Any shortfall between the required technology (Block F) and the useable technology shows up as a technology deficiency (Block G) and identifies the future research opportunities (Block H). Additional future research by NASA (Block J) can increase the controls technology benefits and ultimately nullify the technology deficiency.

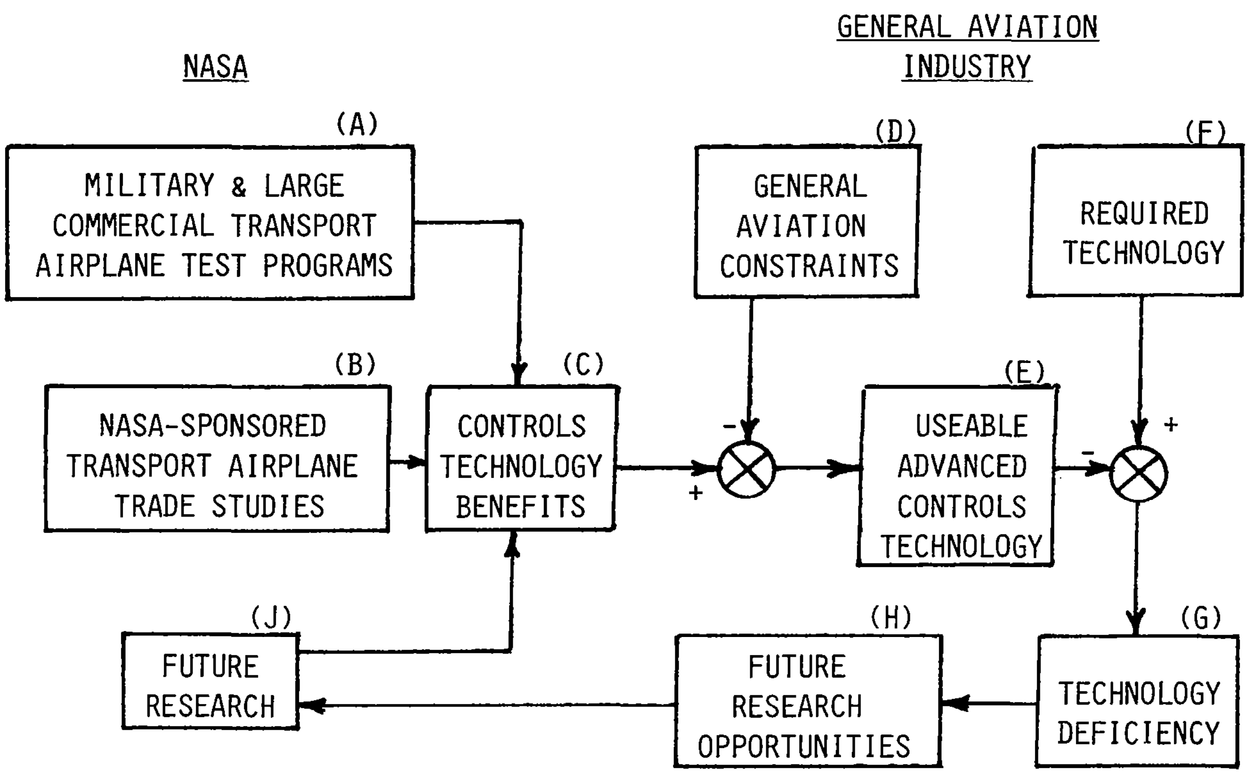

Figure 1

MILITARY AND COMMERCIAL TEST PROGRAMS

A significant number of flight test programs related to ACT have been conducted during the last 25 years. Some of these are shown in Figure 2. Most are related to very large airplanes with flexible structures. The technology is 'acronym saturated'. Richard Holloway defines the more commonly used acronyms and explains system functions in Ref. (1). Those used here are:

CCV.......Control Configured Vehicle
FMS.......Flutter Mode Suppression
GASDSAS...Gust Alleviation & Structural Dynamic Stability Augmentation System
ALDCS.....Active Load Distribution Control System
AS........Augmented Stability
WLA.......Wing Load Alleviation

- B-52.........................CCV, FMS
- XB-70........................GASDSAS
- YF16.........................AS
- C-5A.........................ALDCS
- L-1011.......................WLA

Figure 2

NASA-SPONSORED TRADE STUDIES

A few of the many trade studies sponsored by NASA are shown in Figure 3. These all relate to commercial transports or commuter airplanes. The STAT program, which started in 1978, was reported by Louis Williams of NASA Langley at the 1982 SAE Commuter Aircraft and Airline Operations Meeting in Savannah, GA (Ref. 4). The report contains much material relevant to the application of advanced technologies in the general aviation industry. ACT benefits were explored on two candidate airplane designs. Controls technology benefits need to be separately identified.

1970 - LOW WING LOADING STOL STUDY(2)....................NASA/BOEING WICHITA

1972 - APPLICATION OF ADVANCED TECHNOLOGIES
TO LONG-RANGE TRANSPORT AIRCRAFT(3)...............NASA/BOEING SEATTLE

1978 - SMALL TRANSPORT AIRCRAFT TECHNOLOGY
(STAT) PROGRAM(4)................................NASA/INDUSTRY

1982 - INTEGRATED APPLICATION OF ACTIVE
CONTROLS TECHNOLOGY TO AN ADVANCED
SUBSONIC TRANSPORT(5)............................NASA/BOEING SEATTLE

Figure 3

CONTROLS TECHNOLOGY BENEFITS (TEST RESULTS)

Some of the benefits which have been obtained as a result of the flight test programs are listed in Figure 4. Active control systems on the B-52 and on the C-5A are incorporated as retrofits to production airplanes. The L-1011 systems permit increased wing span which leads to improved cruise performance.

- ECP 1195 ON B-52 REDUCES FATIGUE & ALLEVIATES GUST LOADS
- ALDCS ON C-5A IMPROVES FATIGUE LIFE BY GUST AND MANEUVER LOAD REDUCTIONS
- L-1011 SYSTEMS REDUCE LATERAL GUST DESIGN LOADS AND PERMIT WING TIP EXTENSION WITH NO BEEF-UP

Figure 4

CONTROLS TECHNOLOGY BENEFITS (TRADE STUDIES)

NASA-sponsored trade studies have shown significant synergistic design benefits for a wide range of commercial airplane types. Some results from these studies are shown in Figure 5 for STOL, commuter, and subsonic commercial transport airplanes.

GLA.....Gust Load Alleviation
PAS.....Pitch Augmentation System
AAL.....Angle-of-Attack Limiting

- REF.(2) STOL STUDY SHOWS 10% TO 30% GROSS WEIGHT REDUCTION WITH MECHANICAL FLAP 'GLA' (F.L. < 2500 FT.)
- REF.(3) MACH 0.98 AIRPLANE GROSS WEIGHT REDUCED BY 11% THROUGH USE OF 'AS'
- REF.(4) 'ACT' BENEFITS CONVAIR & LOCKHEED COMMUTER AIRPLANE DESIGNS
- REF.(5) 10% IMPROVED FUEL EFFICIENCY ON SUBSONIC TRANSPORT THRU USE OF PAS, AAL & WLA

Figure 5

GENERAL AVIATION 'ACT' CONSTRAINTS

The constraints listed in Figure 6 are typical of some which might be specified by the general aviation industry. Coordination within the industry is required before these can be considered as an official industry input. However, judging from the complexity levels of systems in use today, constraints such as these will produce significant future research opportunities. The need to be compatible with manual (unpowered) primary flight control systems was addressed by Dr. Jan Roskam and others in Ref. (6). This considered the use of a separate surface stability augmentation system for general aviation aircraft. Design philosophies and hardware implementation schemes were defined and evaluated in Ref. (7).

- MUST BE SIMPLE
- MUST BE EASY TO MAINTAIN
- MUST NOT BE SAFETY CRITICAL
- MUST BE COMPATIBLE WITH MANUAL (UNPOWERED) PRIMARY FLIGHT CONTROL SYSTEMS
- MUST IMPROVE AIRPLANE SALES POTENTIAL

Figure 6

GENERAL AVIATION FLIGHT TESTS

General aviation constraints such as those just mentioned have been recognized for some time. As a result, several NASA 'ACT' programs have been directed specifically towards the general aviation type of airplane. A recent review has been presented in Ref. (8) by Dr. David Downing and others of KU. A few of the programs are listed in Figure 7.

VRS..........Vertical Ride Smoothing
GPAS.........General Purpose Airborne Simulator
RSS..........Relaxed Static Stability
SSSAS........Separate Surface Stability Augmentation System

C-45...................VRS

C-140..................GPAS/RSS

BEECH 99...............SSSAS

Figure 7

10^{-3} BUMP SIZE

The potential need for ride quality control on some commuter airplanes can be seen by comparing the estimated ride quality of various types of unaugmented airplanes. Figure 8 shows the estimated 10^{-3} bump size for three types normalized to that of a commercial transport flying at an altitude of 35,000 feet. It is apparent that the commuter with its relatively high response to vertical gusts flying in the more gust-prone lower altitude bands will present a rougher ride in turbulent conditions. Technology trends in many of the emerging new commuters are towards simplicity, and it may be some time before ride quality systems are generally accepted. Research should continue to take advantage of the rapid developments in electronics and controls to make these systems more attractive for future high-technology commuter airplanes.

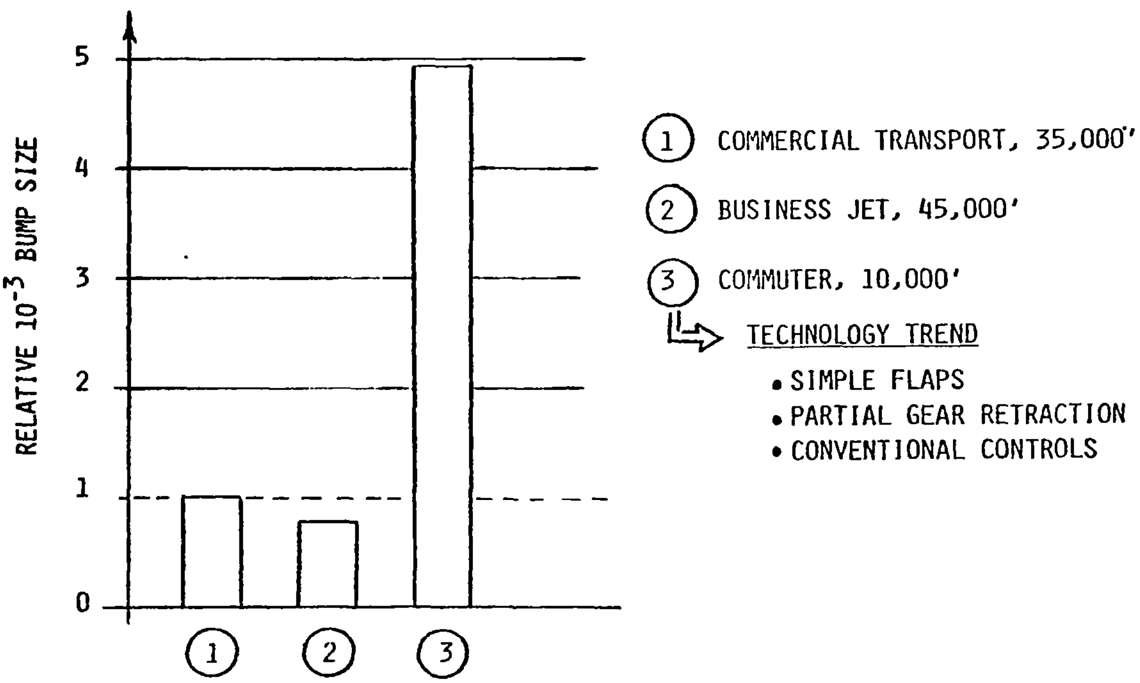

Figure 8

TECHNOLOGY CHOICES

General aviation airplane designers tend to use simpler control technologies than those employed on military and large commercial transport airplanes. As a result, a larger reserve of well-proven controls technology is available as an alternative to the adoption of advanced state-of-the-art controls technology. This is depicted in Figure 9.

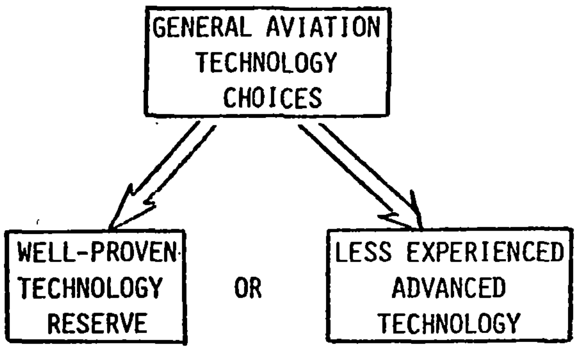

Figure 9

SOME GENERAL AVIATION PREFERENCES

A brief list of some general aviation airplane design preferences is presented in Figure 10. This is included to emphasize a point that in many instances a simple technology is chosen over a more complex and more effective one. The tendency to use simple flap systems and low wing loadings is an example of the 'trade towards simplicity' approach. Quite often there is a tendency to reject any beneficial external features if they are considered detrimental to styling, and the preference is to eliminate avionic systems rather than to add them. Clearly much research will be required to produce ACT benefits which are marketable in the general aviation sector.

- SIMPLE FLAPS & LOW WING LOADINGS
- CONFIGURATION FEATURES WHICH ARE BOTH BENEFICIAL & STYLISH (E.G., WINGLETS)
- MINIMAL DEPENDENCE ON AVIONIC SYSTEMS (E.G. YAW DAMPERS, STALL PREVENTION)

Figure 10

SIMPLE FLAPS AND LOW WING LOADINGS

The 'trade-towards-simplicity' tendency just noted is seen from the data presented in Figure 11. This compares the stall speeds and wing loadings of some general aviation airplanes with those for commercial transports and advanced high-lift airplanes. In general, the landing $C_{L_{MAX}}$ for the general aviation types is around 1.8, which is achievable by simple single-slotted partial span flaps. The commercial transports have a landing $C_{L_{MAX}}$ close to 2.8, which requires more complex flap arrangements. The general aviation landing stall speeds are kept to an acceptable level by using lower wing loadings than are commonly used by the commercial transports. Clearly there is some tradeability towards more complex flaps to obtain the cruise benefits of a higher wing loading. This is an example of an available technology not being fully exploited due to the preference for simplicity. Similar trends were noted by Dr. Jan Roskam, Ref. (9), who proposed new airfoils, higher wing loadings, and a new look at general aviation airplane design.

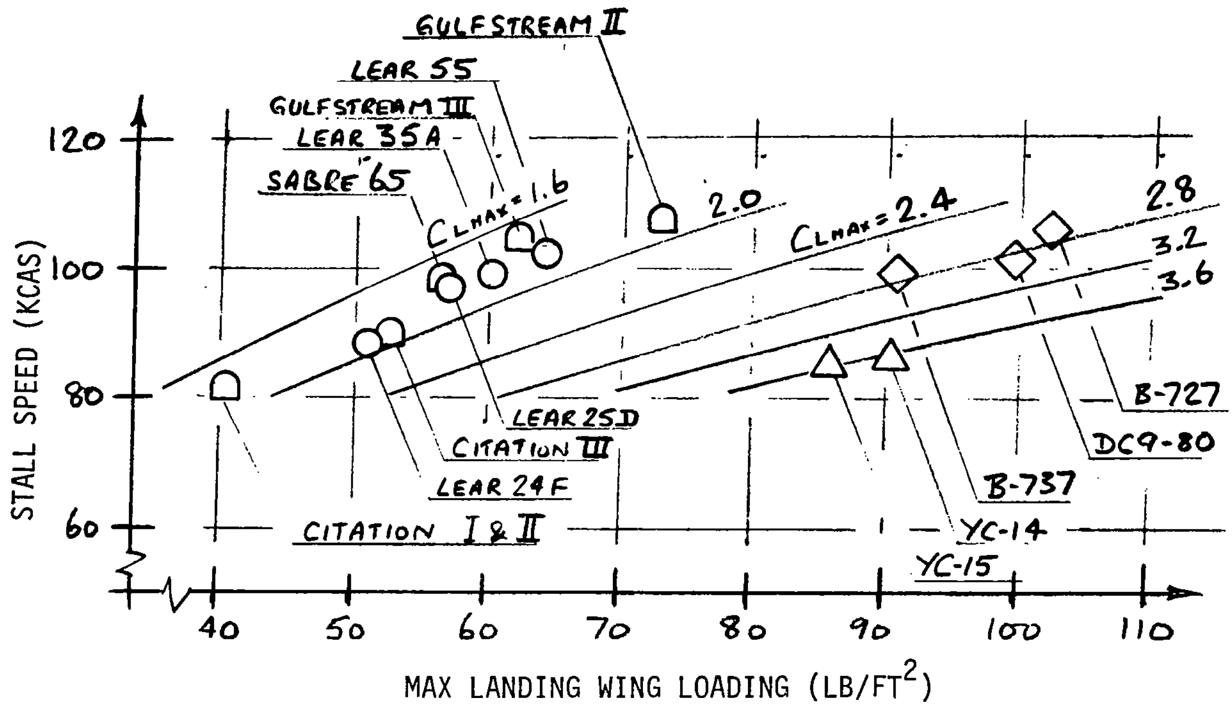

Figure 11

THE MAGNITUDE OF AIRPLANE PERFORMANCE BENEFITS

Quite often the magnitude of airplane cruise performance benefits available from ACT is small (e.g., 2 or 3 percent). While such improvements cannot be ignored, the cost effectiveness of systems needed to obtain them must be carefully considered. A basic requirement must be that the improvement will be sustained throughout the life of the airplane and that the benefits definitely will be felt by the airplane owner.

To give some indication of performance improvement 'detectability', data on airplane fleet performance variability are presented in Figure 12. This is a histogram of incremental percentage fuel flow gathered from forty-one new production airplanes all of the same model designation and all flown on the same route by production flight test crews. Data were corrected for observed ambient conditions. About half the measurements are contained within ±2% of the nominal value.

Even though a cruise performance 'improver' ACT system might make a small but statistically significant improvement to the fleet picture, it may not be of any practical significance to a particular one-airplane operator.

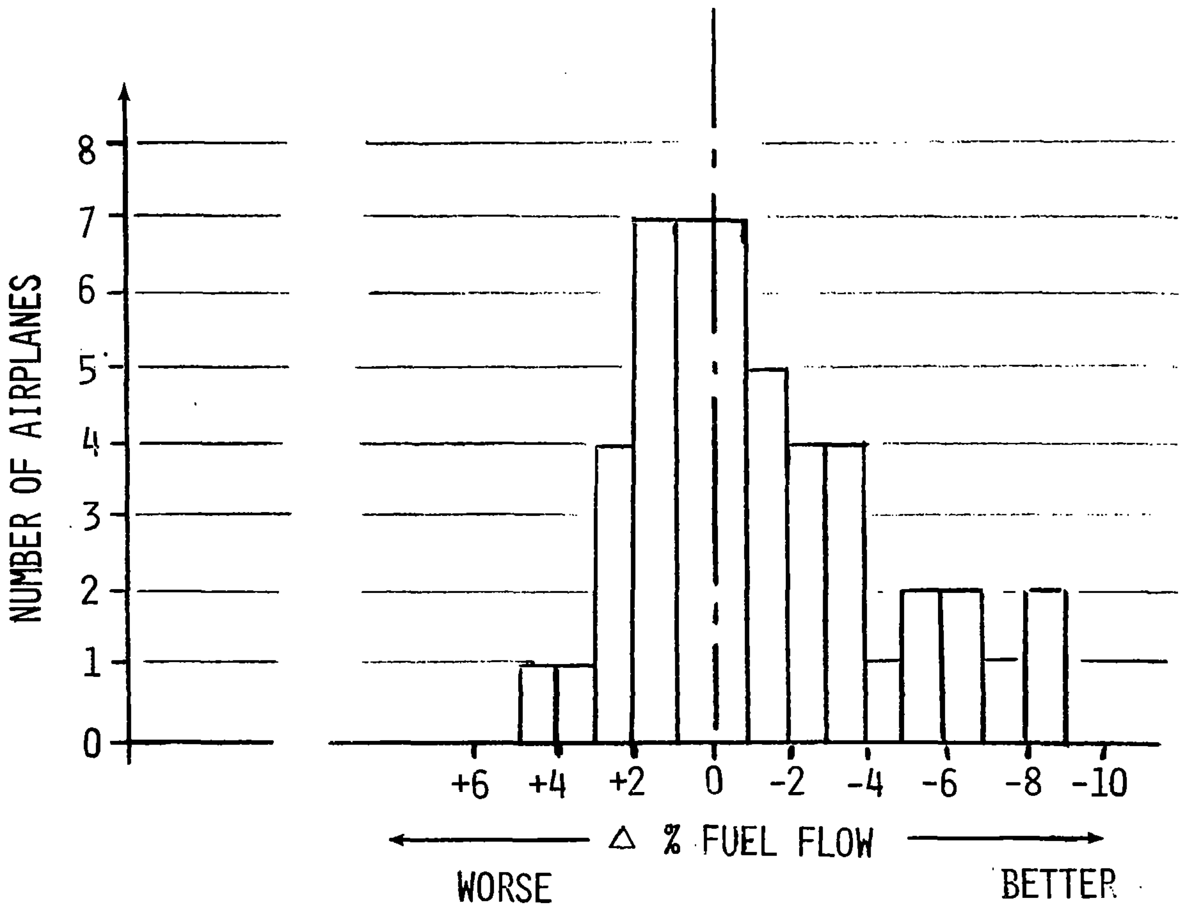

Figure 12

ACT USED IN TOUGH COMPETITIVE SITUATIONS

Williams (Ref. 4) wrote that "...competitive pressures will accelerate the use of technological advances...". The data in Figure 13 confirm this statement and show how ACT was introduced in a tough competitive situation between two general aviation business airplanes. The cruise performance of each airplane is comparable with airplane A's passenger miles per pound of fuel used being better than B's on the short range. The higher wing loading and winglet used on airplane 'A' more than offsets the low wing loading and supercritical section of airplane 'B'. Then, airplane A's balanced field length was made comparable with B's by introducing automatic performance reserve (APR) and automatic spoilers. These change engine thrust and spoiler setting without a direct command from the pilot and therefore can be classified as active control systems.

AIRPLANE	W/S	AR	$\Lambda_{.25}$	SECTION	WINGLET	PERFORMANCE			
						PARAMETER/RANGE	300 NM	600 NM	1500 NM
A	79.4	6.72 (7.92)*	13°	NACA 64 (MODIFIED)	YES	PM/LB	1.13	1.35	1.48
						FLT. TIME	0 + 45	1 + 26	3 + 35
						BFL(1)	3,150	3,400	4,400
B	64.1	8.94	25°	SUPER CRITICAL	NO	PM/LB	0.93	1.22	1.48
						FLT. TIME	0 + 44	1 + 30	3 + 43
						BFL	3,200	3,420	4,200

*WINGLET EFFECT INCLUDED.

(1) BFL IMPROVED WITH APR & AUTOSPOILERS.

Figure 13

GENERAL AVIATION ACT SUGGESTIONS

Based on the very brief discussion of some general aviation design trends and preferences (still to be coordinated within the industry sector), Figure 14 presents a summary of suggestions for ACT activities. It seems that avionic cruise performance improvers will not sell easily unless the advantages are large. Since many general aviation airplanes have low wing loadings and fly at relatively low altitudes, the emphasis should probably be on ride quality improvement and gust alleviation systems. Retrofittable systems could be attractive since few airplanes are likely to be designed with optimal structures and no growth capability.

- 'CRUISE IMPROVERS' SHOULD:
  - A) COMPLY WITH CONSTRAINTS
  - B) COMPETE WITH FLAP/WING-LOADING TRADE-OFF.
  - C) PRODUCE SIGNIFICANT REDUCTION IN CRUISE FUEL-FLOW.
- RIDE CONTROL & GUST ALLEVIATION SYSTEMS MAY BE MOST LIKELY 'ACT' FUNCTIONS TO FIND APPLICATON
- RETROFITTABLE LOAD ALLEVIATORS MIGHT BE ATTRACTIVE FOR PROVIDING AIRPLANE GROWTH CAPABILITY WITH MINIMUM STRUCTURAL BEEF-UP.

Figure 14

GENERAL AVIATION CCV

Information and discussion presented so far might give the impression that the general aviation industry is ultra-conservative and not likely to adopt any significantly new controls concept in the forseeable future. However, even though there may be a natural reluctance to adopt a complicated avionics ACT system, the field of 'non-electronic' CCV technology might be regarded differently. The new designs introduced by Beech and by the Gates-Piaggio team at this year's National Business Aircraft Association (NBAA) show in Dallas show once again that "...competitive pressures will accelerate the use of technological advances..." (Ref. 4). Figure 15 shows the competitive 'canard' and 'three-surface' designs relative to a conventional configuration. NASA research has been strongly supportive of these unconventional designs. Much is left to be done.

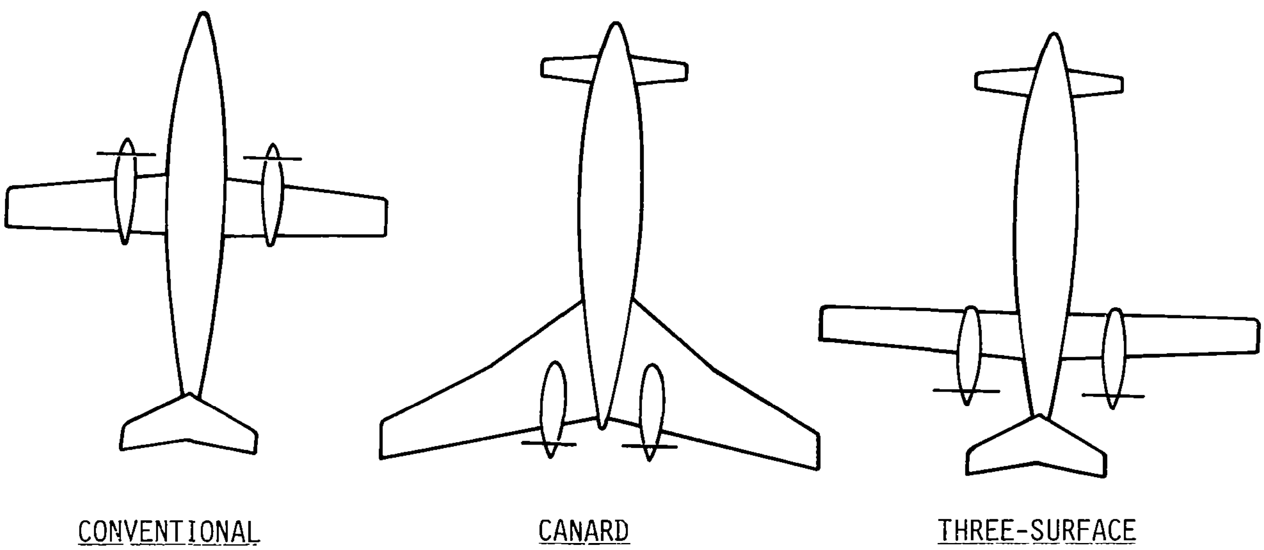

Figure 15

GENERAL AVIATION RESEARCH OPPORTUNITIES
IN THE FLIGHT CONTROLS TECHNOLOGY

The research opportunities in the fields of ACT and CCV for general aviation are enormous. This review has attempted to forsee some of these opportunities by assessing general aviation needs and trends relative to the currently available technology. A few ideas are listed in Figure 16. Coordination within the general aviation industry and between industry and NASA should be intensified in the near term to try to provide NASA with a more complete and representative feedback.

A) OVERALL

- CONTINUE STAT FOR SMALLER G.A. AIRPLANES (<10 PAX.)
- DETERMINE POTENTIAL 'ACT' CONTRIBUTION
- CATALOG ALL ACT BENEFITS.

B) AVIONIC SYSTEMS

- EXPLORE FEASIBILITY OF RETROFITTABLE LOAD ALLEVIATORS & RIDE QUALITY IMPROVERS.
- RUN SIMULATOR STUDIES & FLIGHT TESTS.
- DEVELOP ANALYTICAL METHODS AFFORDABLE TO GENERAL AVIATION USERS

C) AIRPLANE CONFIGURATIONS

- INCLUDE CANARDS & THREE-SURFACE AIRPLANES IN A) & B) ABOVE.
- CONTINUE WIND TUNNEL TESTS TO DETERMINE THE STABILITY AND CONTROL CHARACTERISTICS OF UNCONVENTIONAL AIRFRAME/ PROPULSION ARRANGEMENTS

Figure 16

REFERENCES

1. Holloway, Richard B., "Introduction of CCV Technology Into Airplane Design," AGARD-CP-147, vol. 1, June 1974, pp. 23-1 to 23-16.

2. Holloway, R. B., Thompson, G. O., and Rohling, W. J., "Prospects for Low-Wing-Loading STOL Transports With Ride Smoothing," Journal of Aircraft, volume 9, no. 8, August 1972, pp. 525-530.

3. Boeing Co., "Study of the Application of Advanced Technologies to Long Range Transport Aircraft," NASA CR-112093, May 1972.

4. Williams, Louis J., "Advanced Technology for Future Regional Transport Aircraft," SAE 1982 Transactions, vol. 91, section 3, 1982, pp. 2481-2497.

5. Boeing Co., "Integrated Application of Active Controls (IAAC) Technology to an Advanced Subsonic Transport Project," NASA CR-165963, December 1982.

6. Roskam, J., et al., "An Investigation of Separate Surface Stability Augmentation Systems for General Aviation Aircraft," University of Kansas, Center for Research, Inc., August 1972.

7. Roskam, J., "Design Philosophy & Hardware Implementation of Separate Surface Automatic Flight Control Systems," University of Kansas, Center for Research, Inc., May 1974.

8. Downing, D., Hammond, T., and Amin, S., "Ride Quality Systems for Commuter Aircraft," NASA CR-166118, May 1983.

9. Roskam, J., "New Airfoils and Higher Wing Loadings: A New Look at General Aviation Airplane Design," University of Kansas, Center for Research, Inc., May 20, 1974.