PILOT CONTROLS AND SPIFR FLIGHT

D. R. Downing
Flight Research Laboratory
The University of Kansas

A study was performed to determine the relative advantages and disadvantages of four candidate pilot control devices for use by a single pilot flying a general aviation aircraft in instrument meteorological conditions. Only the pitch and roll axes were considered. The control devices examined were the wheel-yoke, center-stick, Brolley handles, and side-arm controller. Qualitative evaluation criteria were established that included instrument panel visibility, control sensitivity, pilot comfort, and space requirement behind the instrument panel. The results of the study indicated that the side-arm controller offered the possibility of an improvement, but further research was necessary to determine its feasibility.

To assist in the discussion, it is useful to define certain terms related to a manual or reversible control system. The system is composed of three main subsystems: the control surface, the actuation system, and the pilot controller. The actuation system is usually implemented by cables or push rods. The pilot controller is the device the pilot uses to input his commands and is most often a wheel or center stick.

"MANUAL" AIRCRAFT CONTROL SYSTEM

- CONTROL SURFACE
- ACTUATION SYSTEM
- PILOT CONTROLLER

This study was aimed at examining several candidate pilot controllers and determining the relative advantages and disadvantages specifically for the single pilot flight in Instrument Meterological Conditions. The details of the study are documented in two NASA contractor reports (References 1 and 2). Only the pitch and roll axes were considered.

OBJECTIVE: INVESTIGATE THE APPLICABILITY OF SEVERAL PILOT CONTROLLERS FOR THE SPIFR MISSION

APPROACH:

- ESTABLISH QUALITATIVE CRITERIA
- COLLECT DESIGN DATA
- EVALUATE CANDIDATE CONFIGURATIONS
- IDENTIFY AREAS FOR FUTURE INVESTIGATION

The design of a manual control system is subject to FAA certification requirements as listed below. The designer then has at his disposal a set of design variables related to the control system.

MANUAL CONTROL SYSTEM DESIGN

FAR REQUIREMENTS

- MAXIMUM CONTROL FORCE LIMITS
- CONTROL TRAVEL LIMITS
- STICK FORCE PER G
- STICK FORCE SPEED VARIATION

DESIGN VARIABLES

- CONTROL SURFACE GEOMETRY (AREA & CHORD)
- CONTROL SURFACE AIRFOIL (HINGE MOMENT)
- GEARING RATIO
- MASS BALANCING
- ASSIST SYSTEMS

The important design variable at the pilot/vehicle interface is stick force, F_s. It is related to the actuator system gear ratio, G, and the hinge moment, HM. The hinge moment in turn is related to the area of the control surface, S; its chord, $\bar{c}$; the hinge moment coefficient, C_h; and the dynamic pressure, $\bar{q}$.

CONTROLLER STICK FORCE

$F_S = G \cdot HM$

G = GEARING

HM = HINGE MOMENT = $\bar{q}\ S\ \bar{c}\ C_h$

To compare candidate pilot controllers, evaluation criteria were established. The elements listed below, constituting the criteria, were selected after a review of typical single pilot IFR missions. No relative weighting of importance of the four elements was established.

SPIFR Controller Evaluation Criteria

- Instrument Panel Visibility
- Control Response or Sensitivity
- Comfort or Pilot Fatigue
- Space Required Behind the Instrument Panel

The four candidate controller mechanizations are listed below. As mentioned earlier, only control of the pitch and roll axes was considered. The yaw axis was assumed to use standard rudder pedals in all cases. A separate chart will be used to discuss each of these options, and supporting charts will illustrate specific points.

CANDIDATE PILOT CONTROLLERS

- WHEEL AND YOKE
- CENTER STICK
- BROLLEY HANDLES
- SIDE-ARM CONTROLLER

Although it is the industry standard, the wheel yoke mechanization has several disadvantages including mechanical complexity, large requirements for space behind the panel, and obstruction of visibility of portions of the instrument panel.

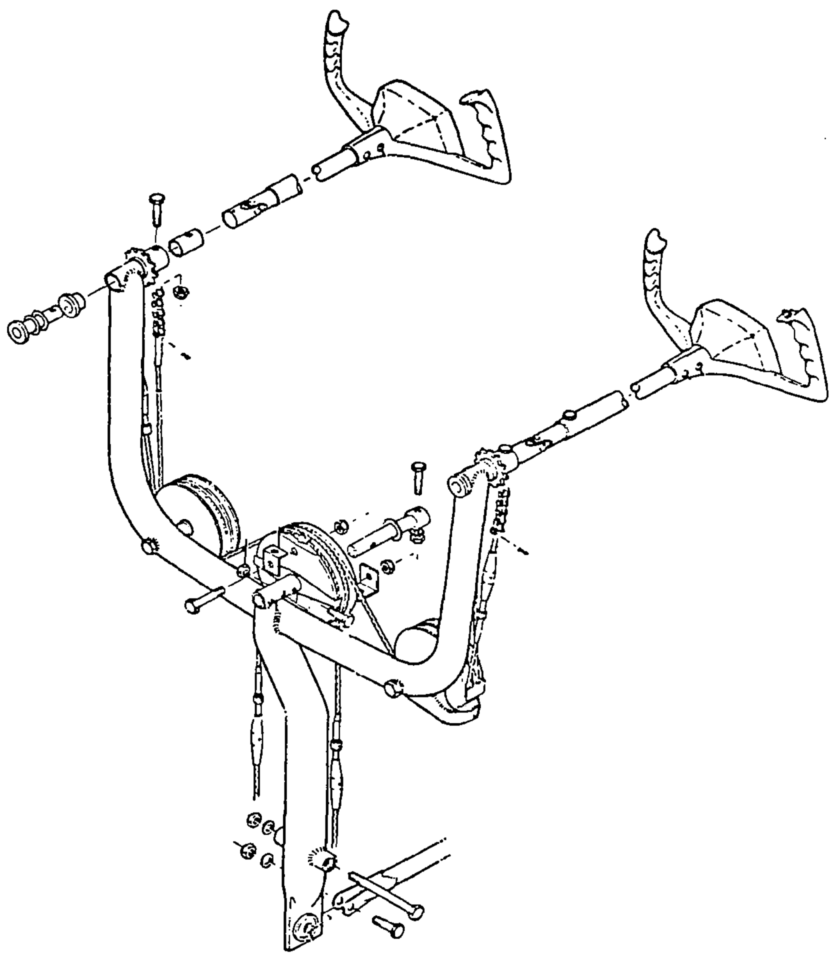
WHEEL YOKE CONTROLLER

- INDUSTRY STANDARD FOR "ALL" NEW COMMERCIAL AIRCRAFT
- STANDARD FOR ALL LARGE AIRCRAFT

ADVANTAGES	DISADVANTAGES
• ADEQUATE MECHANICAL ADVANTAGE	• MECHANICAL COMPLEXITY
• EXTENSIVE BODY OF DESIGN EXPERIENCE	• RESTRICTS SPACE BEHIND PANEL OR FLOOR SPACE
	• RESTRICTS PLACEMENT OF INSTRUMENTS ON PANEL
	• POSSIBLE TO INPUT INADVERTENT COMMAND

MECHANIZATION: DIRECT MECHANICAL LINK

This diagram illustrates the mechanical complexity of a typical behind-the-panel implementation. It also shows the large amount of volume behind the panel that must be dedicated to the controller.



The center stick was the general aviation industry standard until the 1940-1950 period. Reasons for changing to a panel-mounted wheel were not always technical. They included an attempt to relate to driving a car and a concern with women pilots wearing skirts. The center stick is still the standard in military fighters that operate in high g conditions.

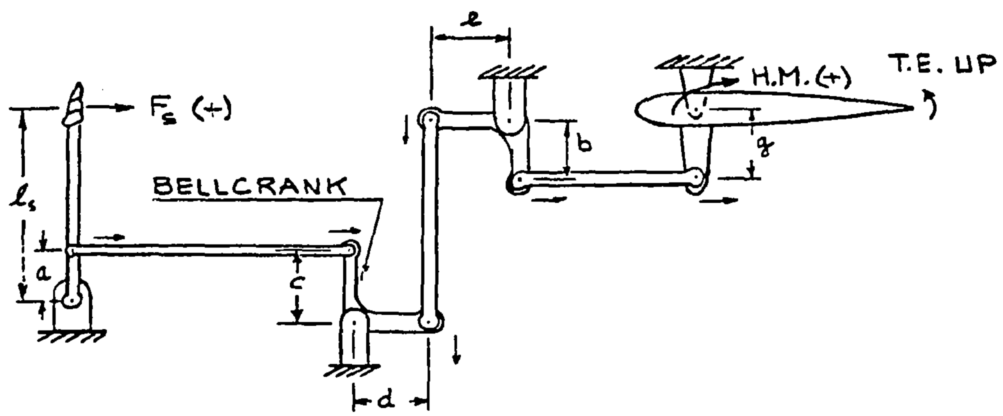
CENTER STICK CONTROLLER

- USED ON "ALL" HIGH PERFORMANCE AIRCRAFT

ADVANTAGES	DISADVANTAGES
• ADEQUATE MECHANICAL ADVANTAGE	• RESTRICTS FLOOR SPACE
• EXTENSIVE BODY OF DESIGN EXPERIENCE	• RESTRICTS MOVEMENT IN COCKPIT
• NO PANEL OBSTRUCTION	
• RELATIVELY SIMPLE MECHANIZATION	

MECHANIZATION: DIRECT MECHANICAL LINK

This diagram from Reference 3 illustrates the typical pitch axis arrangement of gearing between the center stick and the control surface. The large mechanical advantage of this arrangement comes from the ratio ℓ_s/a.



(From ref. 3. Reprinted by permission of the author.)

The Brolley handles were initially developed for the Boeing SST design and are presently implemented in the experimental cockpit of the Boeing 737 used at Langley Research Center. They consist of two controllers, one for each hand, that come out of the instrument panel. Both the roll input (rotation) and pitch inputs (push-pull) are standard, but there is no connection between the handles to obstruct the view of the instrument panel. This mechanization still has the complexity and space-behind-the-panel problems of a conventional wheel.

BROLLEY HANDLES

- EXPERIMENTAL IMPLEMENTATION

ADVANTAGES	DISADVANTAGES
• NO PANEL OR FLOOR RESTRICTIONS	• MECHANICAL COMPLEXITY • RESTRICTS SPACE BEHIND PANEL • NO EXPERIENCE IN GA AIRCRAFT

MECHANIZATION: DIRECT MECHANICAL LINK

The side-arm controller has had extensive use in spacecraft, in research aircraft, and (most recently) in military fighters (F-16). It has also been used in home-built design, e.g. Rutan's Long-EZE and Vari-EZE. Major disadvantages are the limited mechanical advantage and the limited experience in general aviation aircraft.

SIDE-ARM CONTROLLER

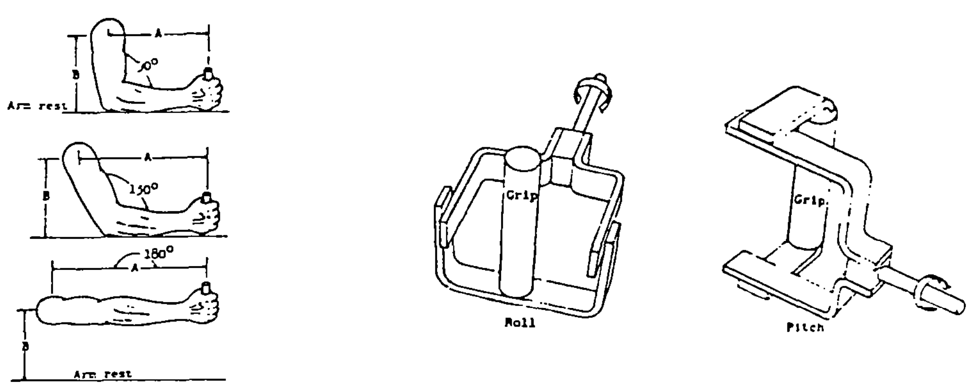
- EXTENSIVE USE IN SPACECRAFT AND RESEARCH AIRCRAFT

ADVANTAGES	DISADVANTAGES
• NO INSTRUMENT PANEL OBSTRUCTION	• LIMITED EXPERIENCE IN GA AIRCRAFT
• NO REQUIREMENT FOR SPACE BEHIND THE PANEL	• LIMITED STICK MECHANICAL ADVANTAGE
• NO OBSTRUCTION IN CABIN	• ONE HAND OPERATION
• PRECISE CONTROL POSSIBLE	
• RELATIVELY SIMPLE MECHANIZATION	

This figure, taken from Reference 4, shows typical data available that defines the mechanical limits (linear and angular) of a side-arm controller.

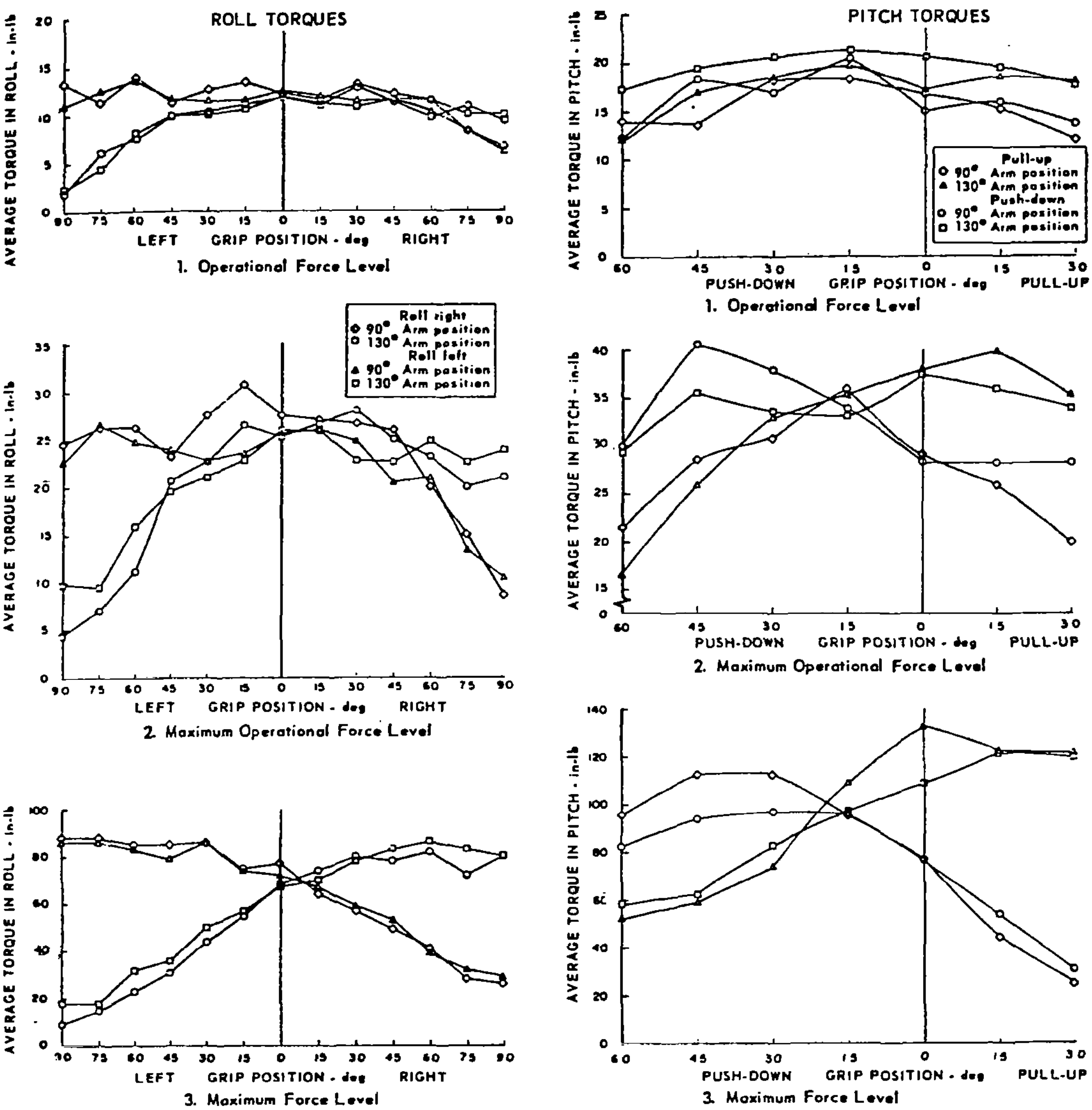
Data for Optimizing Location and Travel of a Side-Stick Controller

Pilot	Distance A in.			Distance B, in.		Maximum controller angle (unconstrained), deg							
						Right Roll		Left Roll		Forward Pitch		Rearward Pitch	
	Measured at elbow angle of -												
	90°	130°	180°	90°	130°	90°	130°	90°	130°	90°	130°	90°	130°
1	15.00	19.00	26.25	13.00	12.50	105	105	80	75	45	35	30	40
2	11.50	18.00	25.00	12.75	11.50	90	100	90	100	65	70	30	30
3	13.00	18.00	25.00	13.00	12.00	90	90	90	95	55	60	30	35
4	12.00	18.00	25.00	13.00	12.00	85	85	75	80	50	45	30	30
5	14.00	18.50	26.00	13.00	12.50	90	95	90	100	60	65	30	30
6	14.50	18.50	27.00	13.75	13.75	90	100	90	100	75	55	45	40
7	12.50	18.00	25.00	12.75	11.50	90	90	105	105	70	75	30	30
8	13.50	18.50	27.00	13.25	13.00	100	95	100	100	80	75	30	30
9	13.30	18.50	27.00	13.25	13.00	90	90	105	105	45	45	40	40
10	13.00	17.50	27.50	13.ˑ75	13.50	90	100	90	105	75	65	55	55
11	14.50	18.75	28.50	13 25	13.75	90	105	90	105	60	75	30	30
Average	13.35	18.30	26 30	13.15	12.63	91.8	96	91.4	97.3	61.8	60.4	34.5	35.0



Preferred Arm Position for Side-Stick Controllers

A second design issue is the stick force level that is possible and acceptable. This figure, from Reference 4, shows typical data available to the control system designer.



These graphs show the forces the pilots could develop at two elbow angles. They were instructed to apply the following levels of exertion:
(1) Operational force--chosen as the comfortable level for continuous control maneuvers;
(2) Maximum operational force--acceptable for short periods, applicable to any maneuver requiring maximum control capability;
(3) Maximum force--the greatest force pilots could exert in each grip position.

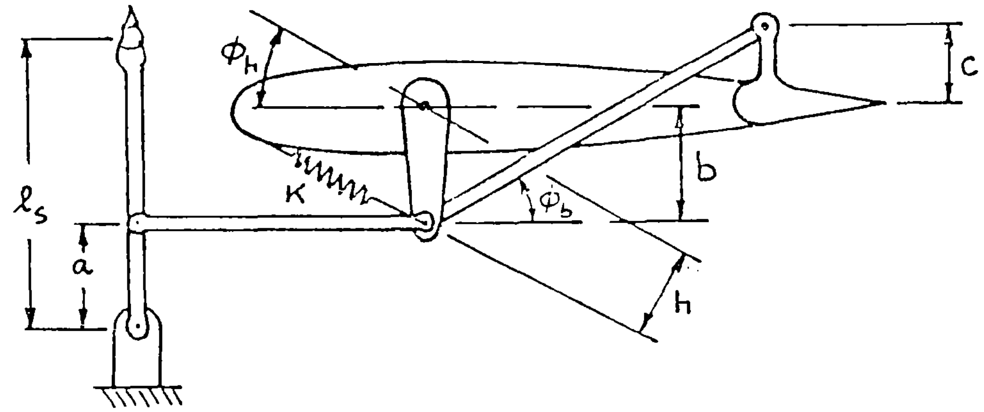
Average Torques Exerted on Side-Stick Controllers

The wheel, center stick, and Brolley handle mechanization all had sufficient mechanical advantage to permit the controller to be directly connected to the control surface. Because of the limits to stick force motion of the side-arm controller, it is probably not possible to use a direct link for all aircraft. Two other possibilities are direct link to a control surface tab, or a boost system. At this time, definitions of "small," "medium," and "large," as used below, are not well established.

SIDE-ARM CONTROLLER MECHANIZATION

"SMALL" AIRCRAFT	DIRECT MECHANICAL LINK
"MEDIUM" AIRCRAFT	MECHANICAL CONNECTION TO TAB
"LARGE" AIRCRAFT	BOOST SYSTEM REQUIRED

This figure, from Reference 3, shows a typical spring tab mechanization for the pitch axis. The aerodynamic gain in this mechanization can compensate for the relatively small value of the mechanical advantage (ℓ_s/a) typical of a side-arm controller.



(From ref. 3. Reprinted by permission of the author.)

A comparison of all controller mechanizations using the wheel as the standard shows that relative to the SPIFR criteria the side-arm controller offers an improvement in all categories.

COMPARISON* OF CONTROLLER OPTIONS

	CENTER STICK	BROLLEY HANDLE	SIDE-ARM
PANEL VISIBILITY	IMPROVED	IMPROVED	IMPROVED
REQUIRED SPACE BEHIND PANEL	LESS	EQUAL OR GREATER	LESS
COMPLEXITY	LESS	EQUAL OR GREATER	LESS
CONTROL SENSITIVITY	GREATER	EQUAL	GREATER

*WHEEL USED AS STANDARD.

To establish the feasibility of using side-arm controllers in future general aviation aircraft, two areas require further research.

FUTURE SIDE-ARM RESEARCH

- QUANTITATIVELY DEFINE "SMALL," "MEDIUM," AND "LARGE" AIRCRAFT FOR SIDE-ARM CONTROLLER APPLICATION.
- INVESTIGATE CONTROLLER SENSITIVITY.

REFERENCES

1. Deam, Dirk J., Michael J. See, Douglas B. Shane, "Pilot Controls and Single-Pilot IFR Flight: Description of Potential Control Devices and Assessment of Their Applicability in General Aviation Aircraft," NASA CR-165738, 1981.

2. Roskam, Jan, "On the Interaction Between Six Types of Cockpit Controllers, Pilots, and Control Surfaces," NASA CR-165755, 1981.

3. Roskam, J., "Methods for Estimating Stability and Control Derivatives of Conventional Subsonic Airplanes," published by the author, Lawrence, Kansas, 1971.

4. Black, G. T., and D. J. Moorhouse, "Flying Qualities Design Requirements for Sidestick Controllers," AFFDL-TR-79-3126, Air Force Flight Dynamics Laboratory, 1979.