Kinematics and arrangement of an active sidestick

S L Samsonovich, N B Rozhnin, A P Larin and M A Makarin
Moscow Aviation Institute (National Research University), 4 Volokolamskoye sh.
Moscow, 125993, Russian Federation

E-mail: mikhailmakarin@gmail.com

Abstract. The article is about design of the active aircraft control sidestick. The disadvantage of
the known frame constructions, apart from the large dimensions, is the difference in the dynamic
characteristics of the channels when using the same actuators, because the mass of a frame
mounted actuator is the load for a fixed base mounted actuator. As a result the kinematic scheme
of an active control sidestick which don’t use a frame is offered. The frameless scheme contains
two identical actuators mounted on the fixed base, at that the interference of channels is excluded.
The derivation of the actuator's gear ratio is given. It is shown that this dependence between the
rotation angle of the actuator output shaft and the handgrip deflection angle is of a sinusoidal
type and that it is close to linear in the range of the handgrip operating angle.

1. Introduction

It is known that the cockpit ergonomics is particularly acute in the design of military aircraft cockpits,
but the gradual introduction of successful solutions in civil aircraft is natural for technical progress.

Increasing safety, reducing the weight and size of aircraft control systems and cost of their production
and maintenance are topical tasks in creating new civil aircraft.

Currently, we can see a gradual transition in using of electrical power grids and electromechanical
actuator systems. It can provide following:

- Significant weight reduction of energy and actuator systems;
- Reducing the cost of aircraft maintenance;
- Increase the maintainability of the aircraft in preparation for the flight, because recovery works
  with electrical equipment is much easier than with hydraulic equipment.

Actuator's kinematics consists of high speed electromotor and high ratio gear to provide big torques
in small dimensions. It is advisable to use the multi-stage transmission as it gives the possibility to vary
and optimize the size of the output link to the required dimensions. In particular, the F-16 cockpit
features required to use a sidestick control, located in the right armrest area of the pilot's seat. This
solution has proven itself well, so few years later, Airbus equipped their A-320 with two sticks but both
sidesticks are passive: their “loading” is achieved with the help of springs, and the handles themselves
are not interconnected.

This caused the question of the development of aircraft control algorithms while simultaneously
rejecting both control posts to different angles. Adding priority buttons partially resolved this issue,
however, new ones appeared related to piloting interference: correcting the actions of one pilot by
another, interfering with the autopilot at the same time by both pilots, the possibility of the appearance
of conflicting signals from control stations and others. This range of issues has been resolved with the
help of data processing algorithms in the on-board computer, but nonetheless the sidesticks remain passive, which does not exclude the occurrence of confusion in piloting, which is called one of the causes of the A-320 crash in 2006. [1, 2]

2. Kinematics analysis

One of the ways to improve the hand controls is to develop active sidesticks which includes actuators. Such active sidesticks may give pilots a tactile sense similar with the mechanical wiring between the steering wheels.

First step is to analyze the kinematics. [3-6] It was found that the most compact arrangement of single motion mechanism may be reached with one rotational (1), one angled (2) and one frame part (3), as shown on figure 1. Rotational motion of part 1 (axis X) converts to swinging motion of part 3 (axis Y). Geometrical interpretation of the mechanism is given on figure 2.

![Figure 1: Kinematics of single motion mechanism](image1)

![Figure 2: Interpretation of the mechanism.](image2)

When shaft 1 rotates on θ from 0 to π, handle angle φ swings from α to -α. And if θ= π/2, φ equals to 0.

The relationship between θ and φ is shown below:

\[ φ = \arctg \frac{BC}{tgθ} = \arctg \frac{tgα \sin θ}{tgθ} = \arctg (tgα \cdot \cos θ) \]  \hspace{1cm} (1)

Figure 3 illustrates the relation when α=30°.
Figure 3. Graphical interpretation of relationship between $\theta$ and $\varphi$ when $\alpha=30^\circ$.

It may be noticed that relation is close to linear when $\varphi$ lies between $\pm20^\circ$ and the "gear ratio" of the mechanism changes from 1.73 in neutral position to 2.3 in maximum.

To create sidestick mechanism with 2 degrees of freedom two such mechanisms was coupled together with a rod 7 as shown on figure 4.

Figure 4. Mechanism with 2 degrees of freedom.

The arrangement makes it possible to provide compact device with high dynamics due to low inertia of the moving parts.

3. Conclusion

It is shown that active sidesticks make it possible to improve situational awareness during the flight.
The arrangement of the most compact device based on swinging motion mechanism is given. The relationship between input and output angle shows that it is almost linear in operation angles. To provide desired forces on handle low speed and high torque actuators are required.

References
[1] Interstate aviation committee air accident investigation commission. Final report on the investigation into accident involving the Armavia A320 near Sochi Airport on 3 May 2006
[2] Hanke D and Herbst C 1999 Active sidestick technology - a means for improving situational awareness *Aerospace science technology*
[3] Kozhevnikov S 1976 *Handbook on mechanisms* (Moscow: Mashinostroenie)
[4] Frolov K, Popov S and Musatov A K 1987 *Theory of Machines and Mechanisms* (Moscow: High school)
[5] Redko P 2007 The concept of steering actuator systems in future aircraft *New frontiers of aeronautical science*
[6] Samsonovich S 2015 Design of embedded electromechanical power hinge mini actuator for electric aircraft concept *More electric aircraft*