SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP6001

Issued 2012-07

Aerospace - Passive Side Stick Unit
General Requirements for Fly by Wire Transport and Business

RATIONALE

More and more commercial transport, military transport and business aircraft are using fly by wire systems controlled from position or deflection side sticks. This ARP is intended to serve the need to have general requirements available for a generic “passive” side stick unit, i.e. without a back drive or active feel force mechanism, that are applicable to these aircraft.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides general requirements for a generic “passive” side stick that could be used for fly by wire transport and business aircraft. It addresses the following:

- The functions to be implemented
- The geometric and mechanical characteristics
- The mechanical and electrical interfaces
- The safety and certification requirements

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP4761 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

ARP4754 Guidelines for Development of Civil Aircraft and Systems

2.1.2 EASA Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS-23 Certification Specifications for Normal, Utility, Aerobatic and Commuter Aeroplanes

CS-25 Certification Specifications for Large Aeroplanes

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

14 CFR Part 23 Code of Federal Regulations, Part 23 Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Category Airplanes

14 CFR Part 25 Code of Federal Regulations, Part 25 Airworthiness Standards: Transport Category Airplanes

2.1.4 RTCA Publications

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160 Environmental conditions and test procedures for airborne equipment

RTCA/DO-178 Software Considerations in Airborne Systems and Equipment Certification

RTCA/DO-254 Design Assurance Guidance for Airborne Electronic Hardware Considerations in Airborne Systems and Equipment Certification

2.1.5 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-STD-461 Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests.

MIL-STD-883 Test Method Standard Microcircuits

MIL-STD-1797 Flying Qualities of Piloted Aircraft

MIL-E-5400 Military Specification, Electronic Equipment, Airborne, General Specification

MIL-F-83300 Flying Qualities of Piloted V/STOL Aircraft

NASMS33540 General Practices for Safety Wiring and Cotter Pinning

DOD-HDBK-743A Anthropometry of U.S. Military Personnel

2.2 Definitions

2.2.1 Inceptors

Inceptor: A device that is used to provide pilot control inputs and covers a variety of aircraft pilot controls including:

- Side sticks
- Center sticks
- Pedals
- Throttles
- Rotorcraft cyclic and collective controls

Passive Inceptor: A passive control inceptor system primarily generates the artificial feel by passive mechanical elements like springs and dampers to achieve grip force profile gradients without active variation of grip feel forces or position (back drive function).

Passive Side Stick: A passive side stick is a passive inceptor used for pitch and roll (or lateral) control without a back drive or active feel force mechanism.

2.2.2 Specific Side Stick Terms

The definitions of the angular positions/displacements of a left hand side stick are provided in Figure 1.

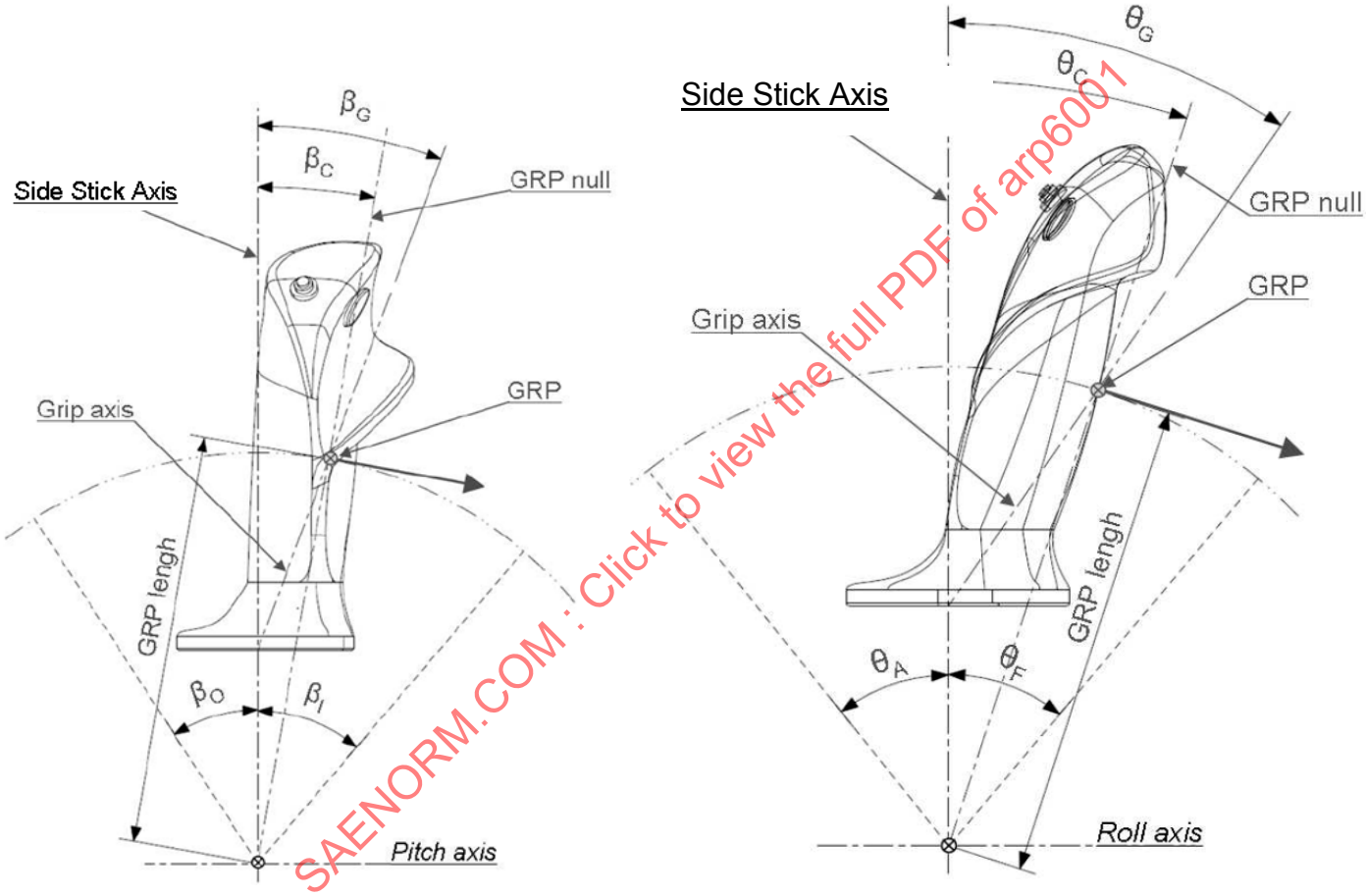


FIGURE 1 - SIDE STICK GEOMETRY DEFINITIONS AT MECHANICAL NULL

Legend:

θ_G GRP Angle null position in pitch regarding the pivot point (side stick axis)

θ_C GRP Angle null position in pitch regarding the mounting face (hand grip axis)

θ_A Side stick angle displacement in pitch in aft direction

θ_F Side stick angle displacement in pitch in forward direction

β_G GRP Angle null position in roll regarding the mounting face (side stick axis)

β_C GRP Angle null position in roll regarding the pivot point (hand grip axis)

β_O Side stick angle displacement in roll in outboard direction

β_I Side stick angle displacement in roll in inboard direction

Grip Reference Position (GRP): The position on the controller/inceptor defined on an interface control drawing, through which grip forces are measured. These force inputs are input perpendicular to the planes defined by the GRP and the rotation axes

Pitch Axis: The axis around which the inceptor grip rotates when the grip is deflected in the pitch direction.

Roll Axis: The axis around which the inceptor grip rotates when the grip is deflected in the roll direction.

The pitch and roll axis are orthogonal and define the reference plane. The specific aircraft application will determine the orientation of this plane relative to the aircraft structure.

Side Stick Pivot Point: The intersection of the pitch and roll axis.

Side Stick Axis: The axis from the pivot point and perpendicular to the side stick reference plan.

Grip Axis: The center line of the grip. The axis through the grip reference position and intersecting the side stick axis at the center of the grip mounting face. This axis may or may not coincide with the side stick axis and may be at an angle to the side stick axis due to human factors considerations.

Mechanical Null or Mechanical Neutral Position: This is the geometric null position of the side stick with no deflection in the pitch or roll axis.

True Position: The grip angular displacement from the mechanical null.

Reported or Sensed Position: The side stick positions measured by the position sensors.

Zero Force Null Band or Null Backlash: The range of inceptor displacement, with no applied force, over which the side stick is statically stable. The zero force null band is typically determined by releasing the side stick from deflected positions and determining where it comes to rest.

Sensed Position Hysteresis: The difference in sensor position signal at the same hand grip position when approached from opposite directions.

Force Hysteresis: The difference in hand grip force when reporting the same hand grip position when approached from opposite directions.

Sensed Position Error: The maximum deviation of the sensor position signal from the nominal sensor output as predicted from the side stick gain.

Position Gradient: The slope of the best fit straight line through a series of sensor outputs corresponding to known sensor positions covering the sensor range.

Sensed Position resolution: The smallest side stick position change that the sensor can measure.

3. FUNCTIONS AND GENERAL DESCRIPTION

The passive side stick described in this document includes the following functions which might be included in the side stick customer specification, depending on the cockpit architecture and other factors.

a. A handgrip which transmits the pilot commands to pitch and roll sensors. Pitch and roll movements can be combined.

b. Position sensors for pitch axis, which provide increasing signals relative to the handle position to flight control computers, their number depending on the system architecture.

c. Position sensors for roll axis, which provide increasing signals relative to the handle position to flight control computers, their number depending on the system architecture.

d. Pitch and roll artificial feel and centering devices.

e. Pitch and roll damping devices.

f. An autopilot break out or a detent that keeps the handgrip at neutral to prevent inadvertent commands while autopilot is engaged. Possibility for pilot to override this locking function by applying a given force.

g. Switches in the hand grip.

h. A redundant structure depending on the safety assessment.

i. Segregated electrical harnesses including aircraft interface connectors.

j. Protection devices against foreign object ingress.

k. Mechanical stops in pitch and in roll axis.

l. Balance mass.

m. An access for a standard rigging pin to hold the handle in neutral position.

n. A tactile indicator operated following a discrete input from flight control computers.

4. INTEGRATION IN THE COCKPIT

4.1 Location in Typical Two-Crew Cockpit

Figure 2 presents a typical flight deck installation.

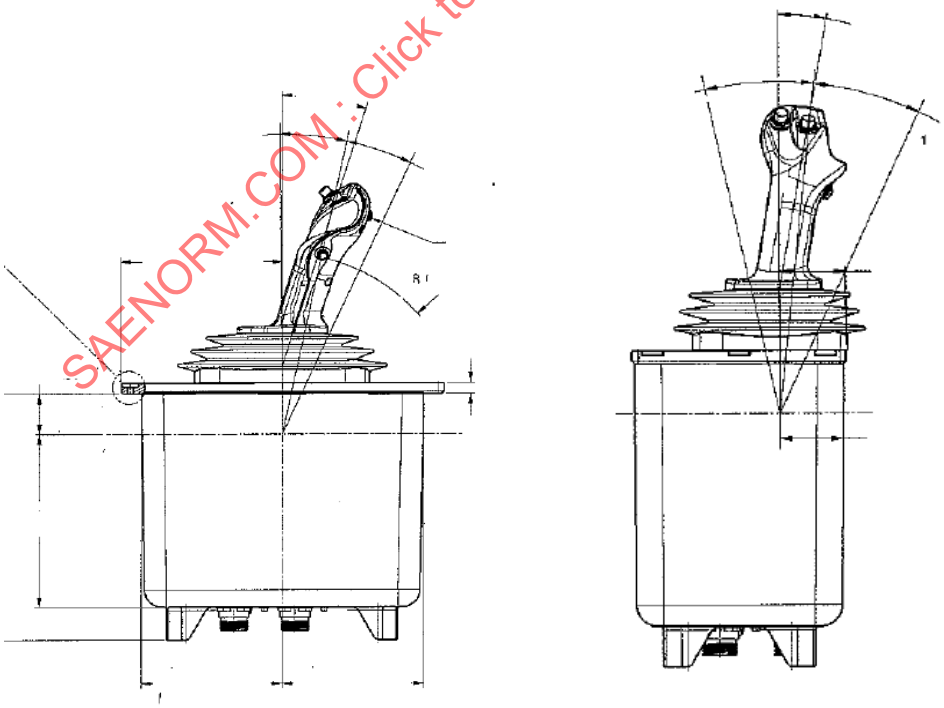
FIGURE 2 - TYPICAL INSTALLATION

The captain and first officer units have the same functionalities and are not mechanically connected.

The geometrical shapes of the captain and first officer units are mirror images to suit left handed and right-handed operation, respectively.

4.2 Envelope and General Geometry

Figure 3 shows a typical envelope for a captain passive side stick.



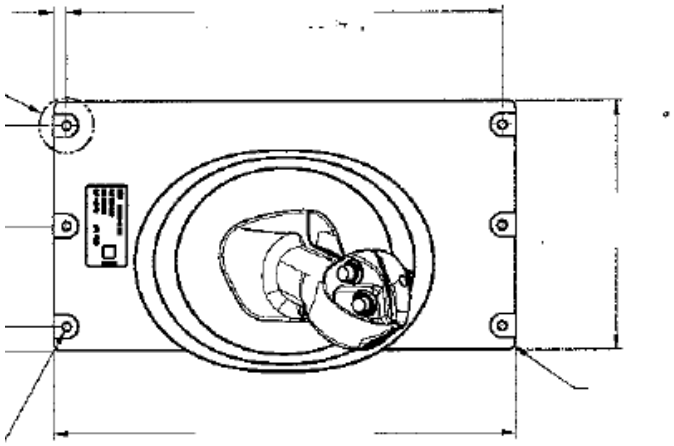


FIGURE 3 - TYPICAL DIMENSIONS OVERVIEW

The key parameters are:

a. Handgrip deflection for both axes

b. Distances from side stick pivot axes to GRP

c. Pivot point position

d. Reference plane position regarding the aircraft structure

e. Mounting face and method of mounting

f. Envelope

g. Mounting surface angles

h. Side stick axis

i. Hand grip shape

j. Side stick position in cockpit

k. Weight and center of gravity location

All this information shall be described in the source control drawing and/or the side stick specification.

4.3 Pilot Validation

The pilot evaluation of the feel of the passive side stick is an important part of validating the specification requirements. In addition to all recommended requirements a specific validation plan should be planned between all parties.

5. DESIGN REQUIREMENTS

This section defines generic design requirements in addition to the certification requirements detailed in 5.1.

Where the requirement is a hard requirement, the wording “shall” is used.

Where the requirement is a generic recommendation but the final value depends of the customer specification, some typical values are proposed.

5.1 Applicable Airworthiness Requirements

5.1.1 Normal, Utility, Acrobatic and Commuter Category Airplanes

The following paragraphs from 14 CFR Part 23/CS 23 Airworthiness Standards are applicable to passive side stick units.

23.397	Limit Control Forces and Torques
23.671	Control Systems - General
23.672	Stability Augmentation and Automatic and Power-Operated Systems
23.673*	Primary Flight Controls
23.675	Stops
23.679*	Control System Locks
23.685	Control System Details
23.1301	Functions and Installation
23.1308**	High-Intensity Radiated Fields (HIRF) Protection
23.1309	Equipment, Systems and Installations
23.1329**	Automatic Pilot System

* CS 23 only

** 14CFR Part 23 only

5.1.2 Transport Category Airplane

The following paragraphs from 14 CFR Part 25/CS 25 Airworthiness Standards are applicable to passive side stick units.

25.397	Control System Loads
25.671	Control Systems - General
25.672	Stability Augmentation and Automatic and Power-Operated Systems
25.675	Stops
25.679*	Control System Locks

25.685* Control System Details

25.1301 Functions and Installation

25.1309 Equipment, Systems and Installations

25.1316 System Lightning Protection

25.1317** High-Intensity Radiated Fields (HIRF) Protection

* CS 25 only

** 14 CFR Part 25 only

5.1.3 FAA Special Conditions

In the absence of specific requirements for side stick controllers, the following applies:

5.1.3.1 Pilot Strength

In lieu of the "strength of pilots" limits shown in 14 CFR Part 25 section 25.143(c) for pitch and roll, and in lieu of specific pitch force requirement of 25.145(b) and 25.175(d), it must be shown that the temporary and maximum prolonged force levels for the side stick controllers are suitable for all expected operating conditions and configurations, whether normal or non-normal.

5.1.3.2 Pilot Control Authority

The electronic side stick controller coupling design must provide for corrective and/or overriding control inputs by either pilot with no unsafe characteristics. The annunciation of the controller status must be provided, and must not be confusing to the flight crew.

5.1.3.3 Pilot Control

It must be shown by flight tests that the use of side stick controllers does not produce unsuitable pilot-in-the-loop control characteristics when considering precision path control/tasks and turbulence. In addition, pitch and roll control force and displacement sensitivity must be compatible, so that normal inputs on one control axis will not cause significant unintentional inputs on the other.

5.2 General Requirements

The side stick should comprise a main body and a handgrip.

The side stick pivot point shall be located in the main body.

The side stick handgrip shall be able to rotate around the side stick axes in the roll and pitch directions.

The pitch and roll axes shall be orthogonal to one another and pitch and roll cross coupling must be minimized.

All forces are to be measured at the GRP, perpendicular to the planes defined by the GPR and the rotation axes.

Typical values are:

- Distance from pivot point to GRP: 6 to 7 in (150 to 180 mm)
- Roll stroke: ±10 to 20 degrees
- Pitch stroke: ±10 to 20 degrees
- Mechanical stroke tolerance: ±0.5 degree

5.2.1 Mechanical Rigging Device

Immobilization at the neutral position might be desired for rigging or safety purpose on ground, using one standard pin, which is typically Φ 0.3125 in (8 mm).

Once the handle is immobilized, the sensors will transmit signals corresponding to 0 degree ± 0.5 degree (typically).

5.2.2 Equipment Finish and Color

The specification shall define:

- The color
- The surface finish and texture for the hand grip
- The foreign object damage (FOD) protection device
- The visible surfaces

Specific care should be taken in the material selection and the protection of these parts to reduce wear over time.

Specific care should be taken to select a texture that allows for good grip (gloved or un-gloved) on the controls.

5.2.3 Mass and Center of Gravity

The center of gravity shall be indicated on the interface control drawing.

NOTE: The typical weight of a side stick is 20 lb (9 kg).

5.2.4 Hard Stop

The side stick shall include pitch and roll hard stops that are capable of withstanding limit and ultimate loads.

5.3 Artificial Feel Requirements

The artificial feel requirements will define regarding either the grip angle (grip displacement) or the sensor angle (sensed position). Figures 4 and 5 show presented artificial feel versus grip displacement.

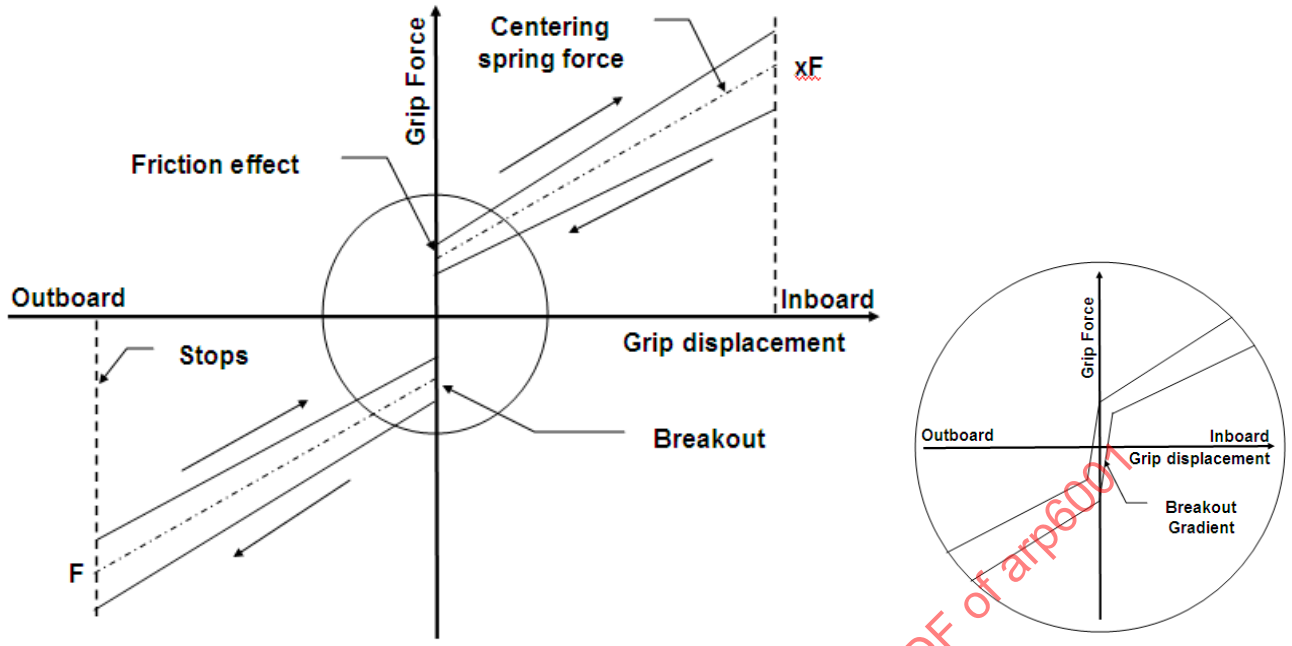


FIGURE 4 - NOTIONAL GRIP FORCE PROFILE IN ROLL

NOTE: F and xF units are Newtons (N).

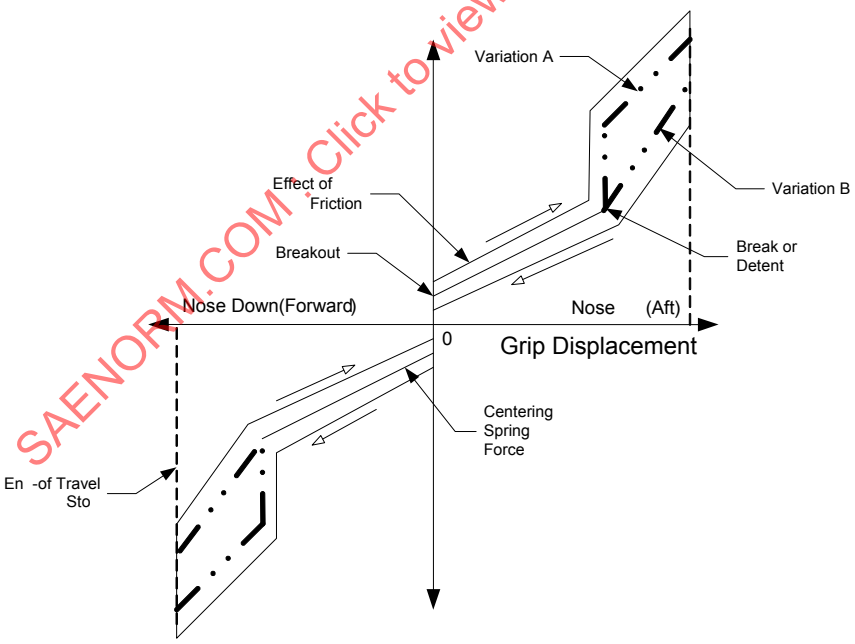


FIGURE 5 - TYPICAL GRIP FORCE PROFILE IN PITCH

NOTE: Variations A and B show typical force/displacement curve shape which might be achieved in a passive side stick.

5.3.1 Breakout and Centering

Refer to Figures 4 and 5.

The handgrip shall return to the neutral position when released from any position outside the zero null force band

The friction levels shall be minimized

The breakout force shall be minimized

The backlash between the handgrip and the feel and damping devices shall be minimized

The customer specification should define acceptable value for these parameters

Typical requirements are:

a. After grip release and return to null, sensors shall transmit signals corresponding to 0 degree ± 0.5 degree

b. The transient motion shall not generate oscillations or overshoot over ±0.5 degree

c. The handgrip must stay centered within ±0.5 degree (typical) when submitted to environmental condition per section 6 and to their combinations, with no autopilot break out engaged:

d. The typical friction value is 0.45 lbf (2 N)

e. The typical breakout force value is 0.9 lbf (4 N)

f. The typical backlash value is 0.01 in (0.3 mm) at GRP

g. The typical breakout gradient is 10 lbf/degrees (45 N/degree) of sensed position (refer to Figure 4)

h. The typical null band is 0.3 degree of sensed position

5.3.2 Autopilot Breakout

An autopilot additional breakout force device may be required. It is to be engaged while the handgrip is in the null region, within a range to be specified.

The autopilot breakout force device may be activated by a discrete signal.

It shall be possible to de-activate the auto-pilot breakout force device in any stick position using an autopilot (A/P) disconnect device.

Typical requirements are:

a. The force that the pilot has to apply to move the handgrip from null in A/P mode:

- Pitch: 10 lbf (45 N)
- Roll: 7 lbf (35 N)

b. The command logic: 28 V: locking active, open circuit: locking inactive

c. The autopilot break out response time: 100 ms

d. The permanent electrical power consumption: 30 W

5.3.3 Grip Force Gradient

The force felt at the handgrip shall be smooth, without any shock or other parasitic feeling, with minimum ripple whatever the position, amplitude, speed or frequency of the commanded movement.

For any combination of pitch and roll deflection, the feel force shall be the vector sum of the pitch and roll forces.

The maximum roll and pitch rate to be considered is 100 degrees/s (typical)

The force gradient shall be defined in the side stick specification.

For Roll, inboard and outboard force gradient shall be specified separately.

For Pitch, one or two force gradients, soft stops could be required.

Typical max deflection static forces are:

- Pitch, nose up and nose down 20 lbf (90 N)
- Roll, inboard 7 lbf (30 N), outboard 4 lbf (20 N)

Typical force gradient tolerance: ±0.1 lbf/degree (0.5 N/degree)

5.3.4 Soft Stop

A soft stop could be defined in pitch or roll to be used by the pilot in specific mode.

Typical soft stop requirement parameters are:

- The break or detent position
- The extra grip force
- The detent gradient
- After detent gradient

5.3.5 Damping Force

A linear or parabolic damping force may be required, with the primary purpose of:

- To prevent handgrip oscillation when released from a deflected position
- To give a feel variation in viscous damping (i.e., variable force per degres per second)
- To slow pilot input in critical stress conditions

5.4 Position Sensors

Both roll and pitch axis shall be mechanically connected to a set of position sensors that transforms their mechanical movement into electrical signals.

For each axis:

- A number of sensors are used by the flight control computers for command or monitoring, the number of sensors depends on the system architecture.
- The sensor drive kinematics shall be compatible with the system accuracy requirement within the full range.
- At neutral position, handgrip position total error as delivered by the sensors (mechanical and electrical error) shall be lower than ±0.3 degree handgrip (typical).
- Within the full range of pitch and roll, handgrip position total error as delivered by the sensors (mechanical and electrical error) shall be lower than ±0.5 degree handgrip (typical). The maximum discrepancy between the signals delivered by two position sensors shall be lower than 1 degree handgrip (typical).
- Sensors shall be suitable for the system interface, duty cycle, reliability and environmental conditions.

Typical sensors types are:

- Rotary Variable Displacement Transmitter (RVDT)
- Potentiometer
- Linear Variable Displacement Transmitter (LVDT)
- Optical or magnetic encoder
- Hall effect sensors

5.5 Dynamics

5.5.1 Inertia

The inertia felt at the GRP shall be minimized (typically <0.1 kg m²)

5.5.2 Feel Dynamics

For analysis purposes the side stick can be defined as a second order transfer function of force to position. In this case the analysis does not include breakout non linearity and static friction.

Pitch and roll axis natural frequency shall be define in the specification.

The damping ratio shall be defined in the specification (typical ratio value = 0.7 to 0.9).

5.6 Handgrip Functionalities and Requirements

The handgrip might include a large number of functionalities depending on cockpit interface concept. The following sections detail typical handgrip functionality.

5.6.1 Tactile Indication Function

In case of the implementation of a tactile indication (i.e., buzzer, shaker), this function shall not induce any commands to the pitch and roll sensors.

Typical requirements for the tactile shaker are:

a. Acceleration and frequency at GRP

b. Maximum current

5.6.2 Grip Switches

Depending on human factors considerations, some functions and switches could be placed in the hand grip, including:

a. A/P disconnect and priority switch

b. Trim control switches for roll or pitch

c. Push-to-Talk (PTT) switch

For these switches, the location in the hand grip, the mechanical specification and the electrical performance should be defined in the product specification.

5.7 Design and Certification Loads

The application of the limit load shall not result in any permanent deformation on mechanical parts.

The application of the ultimate load shall not result in any rupture, ultimate load being equivalent to limit load x 1.5.

The application of the ultimate load ifa rigging pin is installed shall not result in any deformation of the side stick unit.

For all components between and including the handle and its control stops, the limit pilot forces are 250 lbf (1130 N) in pitch axis and 100 lbf (460 N) in roll axis, introduced at the handle grip point level (GRP).

For all other components of the side stick unit, the limit pilot forces are typically 125 lbf (567 N) in pitch axis and 50 lbf (272 N) in roll axis, introduced at the handle GRP; this excludes some components like the internal parts of electrical sensors.

For dual load path architectures, the limit load of each path shall be 100% of the global limit load.

The limit load applied to the push buttons and to the trigger shall be 20 lbf (900 N).

5.8 Life Cycles

The customer specification has to define roll and pitch life cycles for the side stick. Depending of the aircraft model and mission, these life cycles could be very application specific.

The duty cycle definition should take into consideration that the side stick will be subjected to simultaneous roll and pitch movements.

5.8.1 Design Service Life

5.8.1.1 Typical Commercial Aircraft Missions

5.8.1.1.1 Medium Flight Cycle (FC) 300 min and Long Range

The design service life shall be whichever comes first of the following:

- 300 min FC
- 150 000 Flight Hours (FH)
- 30 000 Flight Cycles (FC)
- 25 years

5.8.1.1.2 Short Range

The design service life shall be whichever comes first of the following:

- FC 75 min
- 35 000 Flight Cycles (FC)
- 25 years

5.8.1.2 Typical Regional Aircraft Missions

The design service life shall be whichever comes first of the following:

- FC 120 min
- 90 000 Flight Hours (FH)
- 45 000 Flight Cycles (FC)
- 25 years

5.8.1.3 Typical Business Jet Aircraft Missions

The design service life shall be whichever comes first of the following:

- FC 75 min
- 20 000 Flight Hours (FH)
- 16 000 Flight Cycles (FC)
- 20 years