Digital Flight Controls in Business Aviation

Tuesday, November 1 | 3:00 p.m. – 4:00 p.m.

PRESENTED BY:
Ricardo Carvalhal
Embraer Executive Jets
Conventional Flight Controls
Digital (FBW) Controls

Sensors

Flight Controls Computers

Interface Modules

Remote Electronic Units
Mechanically controlled engines

FADEC controlled engines
Conventional Flight Controls

FBW Flight Controls
FBW Technology History

Apollo Lunar Landing Research Vehicle (LLRV)

• The first pure fly-by-wire aircraft with no mechanical or hydraulic backup
• First flown in 1964
FBW Technology History

Avro Canada CF-105 Arrow (1958)

- The first non-experimental aircraft modified (1972)
FBW Technology History

Several implementations of digital FBW (1970’s)

• Concorde (1969)
• F-8 Crusader, Sukhoi T-4, British Hawker Hunter modified (1972)
Evolution: the third generation

1st generation
- with mixed between electronics and mechanical backup
- e.g.: Pre-Apollo LLRV

2nd generation
- with fully electronics,
- e.g.: Apollo LLRV and 60’s to 80’s implementations

3rd generation
- with full digital electronics, no mechanical backup, highly integrated and closed loop in the three axis.
- e.g.: Recent implementations
The Full Fly-by-Wire era

- Elevator
- Aileron
- Rudder
- Spoiler
## Digital Controls technology moves forward

FBW is making its way into business aviation

<table>
<thead>
<tr>
<th>Heading</th>
<th>Cockpit</th>
<th>Price (US$ Million)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing 777/787</td>
<td>Column and Pedals</td>
<td>150-280</td>
<td>200 – 400 passengers</td>
</tr>
<tr>
<td>Airbus A340/ A380</td>
<td>Sidesticks and Pedals</td>
<td>210-350</td>
<td>300 – 800 passengers</td>
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<tr>
<td>C-Series</td>
<td>Sidesticks and Pedals</td>
<td>N/A</td>
<td>150 – 200 passengers</td>
</tr>
<tr>
<td>Gulfstream G650</td>
<td>Column and Pedals</td>
<td>70</td>
<td>Ultra Long range</td>
</tr>
<tr>
<td>Global 7000/8000</td>
<td>Sidesticks and Pedals</td>
<td>70</td>
<td>Ultra Long range</td>
</tr>
<tr>
<td>Dassault Falcon 7X</td>
<td>Sidesticks and Pedals</td>
<td>53</td>
<td>Ultra Long range</td>
</tr>
<tr>
<td>Legacy 450 / 500</td>
<td>Sidesticks and Pedals</td>
<td>16-20</td>
<td>Mid-light, mid-size</td>
</tr>
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Digital Flight Controls (Fly-by-Wire)

Basic Architecture

- Inputs from sensors and pilots
- Flight Control Laws
- Command flight control surfaces
Digital Flight Controls (Fly-by-Wire)

Example: Legacy 500

Are there hard limits?

Yes, but only where they are really needed:

Controllability

Structural Loads
Normal Flight Envelope

Remaining within Limit Flight Envelope requires side stick out of neutral

With side stick at neutral - aircraft returns to normal flight envelope

Hard limits for controllability & structural loads only

Structural Limits

Max AoA

Max Speed

Max Sideslip

Normal Flight Envelope

Limit Flight Envelope
Fly-by-wire

Enhanced safety is the main benefit

- Overspeed/Underspeed
- Overstress
- Engine failure
- CFIT avoidance

Fly-by-Wire

Enhanced safety

Flying made easy

Optimized performance

Enhanced comfort
The advantages in a business jet

Example: Legacy 450 / 500

- Angle-of-Attack (AOA) limiter as stall protection system
- Enhanced response to CFIT* Avoidance / Wind Shear Escape maneuvers
- Automatic compensation for transients due to configuration changes
The advantages in a business jet

Sidestick

- Cleaner cockpit and better view of displays
- Reduction in weight, maintenance and spare parts
- Force feedback by fix spring and damper
- Inputs from pilot & co-pilot are summed
- Tactile, Aural and Visual warnings in case of dual input
Digital Flight Controls

Underspeed protection: Angle-of-Attack limiter

- Replaces conventional shaker and pusher solutions
- Limits nose up authority instead of pushing the aircraft nose down

AOA Limiter

$$\alpha_{MAX}$$

vs.

Stick pusher

(conventional A/C)
Digital Flight Controls

Overspeed protection

- Engages at speeds beyond Vmo/Mmo
- Airplane can fly closer to structural limits without compromising safety

Overspeed Protection Activation

Nose up command to return to Vmo/ Mmo
Digital Flight Controls

CFIT Avoidance / Wind shear scape

Pilot commands full aft stick/full throttle to achieve maximum climb rate

Better climb with protected aircraft

AOA limit

‘g’ Limit
Digital Flight Controls

Automatic Compensation for failure scenarios

Automatic compensation for configuration changes:

- Roll 100% compensated
- Pitch 100% compensated
- Artificial Yaw

Benefits:

- Predictability: airplane flying feels the same regardless of weight, CG position and speeds
- Reduced transient in the case of a system failure (e.g., engine)

With no pilot action, slightly divergent heading and residual sideslip
Digital Flight Controls

Reduced turbulence

- FBW reacts more effectively than conventional autopilot systems
- FBW control laws reduce aircraft oscillations during turbulence
Operation Modes

Example: Legacy 450 / 500

- **Normal mode** - Workload reduction and Flight Envelope protections
- **Direct mode** - Legacy 500 behaves like a conventional airplane
- Other designs: Normal, alternate and direct modes
- Alternate: one of the axis or protection modes can be degraded
Real life scenarios

In the event of a wake turbulence induced unusual attitude where you find yourself inverted, in a traditional airplane you should:

A. Roll wings level, adjust pitch and power as necessary
B. Declare an emergency with ATC
C. Close your eyes and hope for the best
Real life scenarios

In the event of a wake turbulence induced unusual attitude where you find yourself inverted, in a modern FBW airplane you should:

A. Roll wings level, adjust pitch and power as necessary
B. Declare an emergency with ATC
C. Close your eyes and hope for the best
D. Nothing, if you choose. The airplane will return you to straight and level flight via the shortest route possible. Digital flight control will not allow you to overspeed or over stress the airframe
Real life scenarios

To avoid controlled flight into terrain or escape a microburst in a traditional aircraft, the pilot should:

A. Apply full throttle
B. Calculate best climb speed for maximum rate
C. Ride the shaker
D. All of the above
Real life scenarios

To avoid controlled flight into terrain or escape a microburst in a **modern FBW airplane**, the pilot should:

A. Apply full throttle
B. Calculate best climb speed for maximum rate
C. Ride the shaker
D. Apply full aft stick and full throttle. The plane will calculate max L/D for you.
Real life scenarios

In the event of an engine loss at rotation, your first reaction in a traditional airplane should be to:

A. Compensate for the adverse yaw and roll tendency in the direction of the failed engine and compensate for nose-over pitch
B. Declare an emergency with ATC
C. Reduce thrust in the working engine to match the failed engine
Real life scenarios

In the event of an engine loss at rotation, your first reaction in modern FBW airplane should be to:

A. Compensate for the adverse yaw and roll tendency in the direction of the failed engine and compensate for nose-over pitch.
B. Declare an emergency with ATC
C. Reduce thrust in the working engine to match the failed engine
D. Take your hand off the stick if you’d like. The aircraft will maintain the bank angle and pitch you instruct, with only a slight yaw to keep the pilot “in the loop”.
Real life scenarios

Envelope protection

NTSB 2015 “Most Wanted” list of Safety Improvements:

LOCI Loss of Control in Flight

• “LOCI accidents result in more fatalities in business and commercial operations than any other category of accident over the last decade …”

• “Unintentional stalls occurred in 31 of 71 accidents… Two-thirds of the studied accidents occurred during takeoff, approach or landing with the aircraft below 1,000 feet AGL, affording those crews precious little recovery margin.”
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