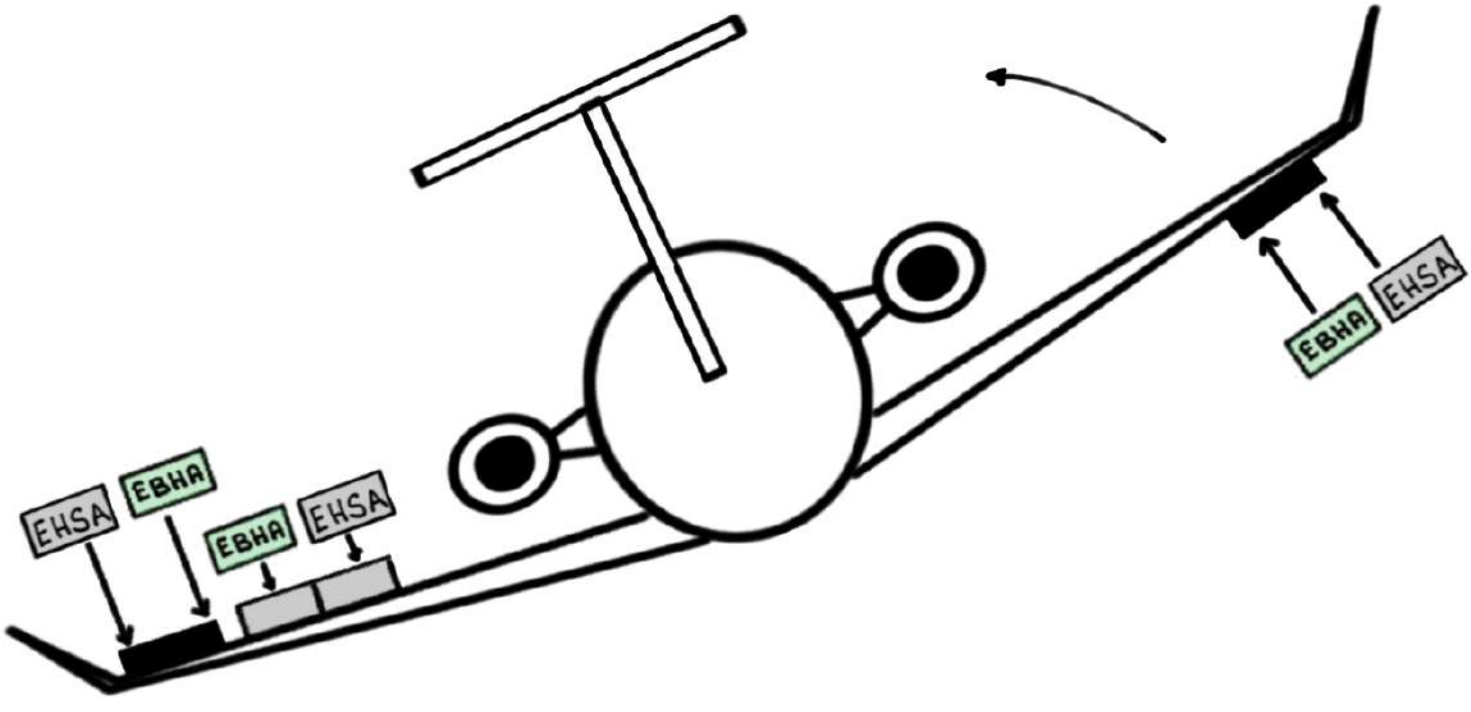
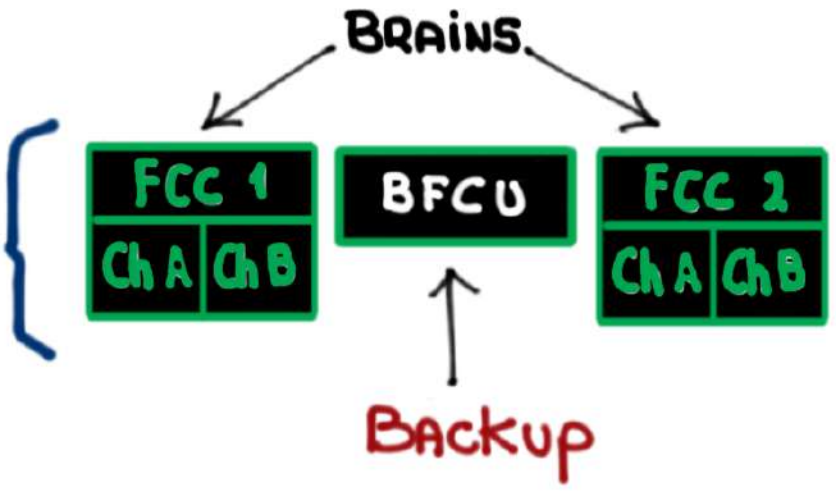
G600 Flight Control System



For study purposes only

Electrically - controlled

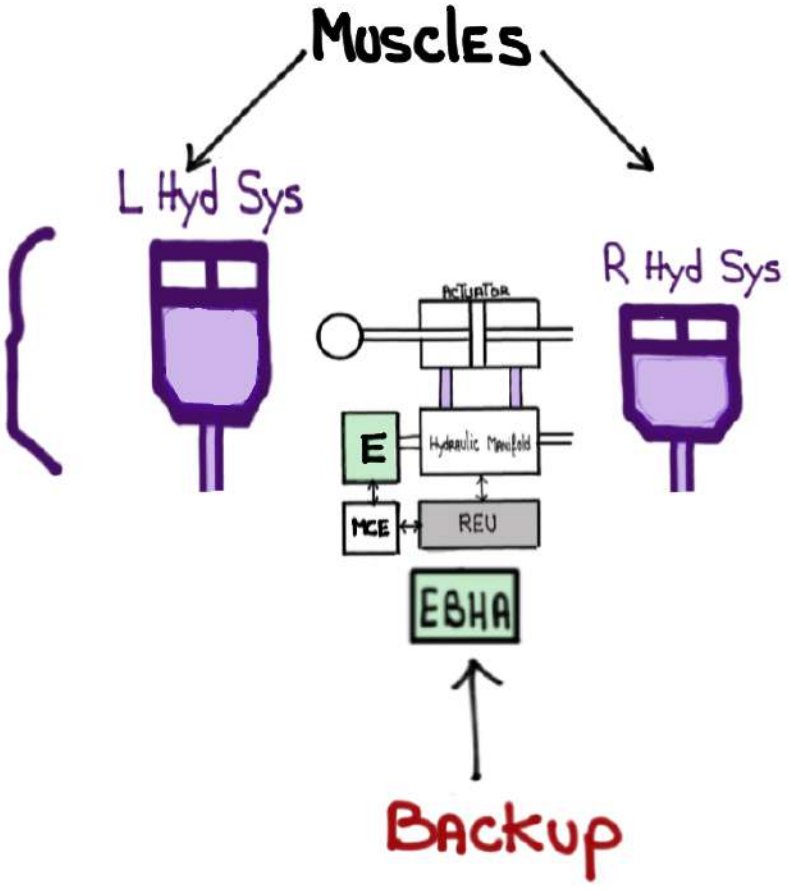


Three (3) axis

Fly-by-wire

Flight Control System
(FCS)

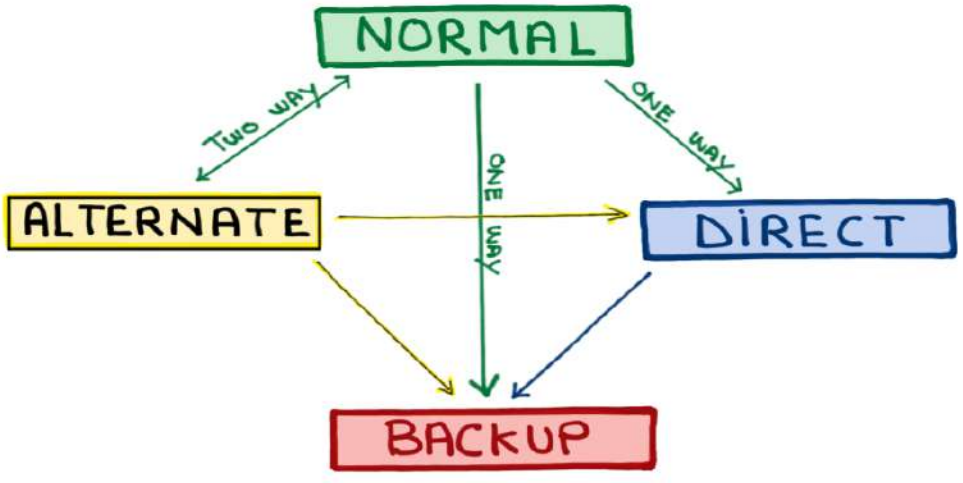
Hydraulically - actuated



ELECTRICALLY - CONTROLLED

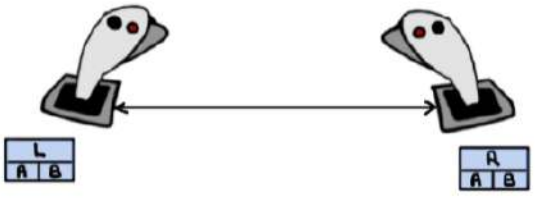
SOFTWARE:

- FLIGHT CONTROL LAWS



HARDWARE:

- ACTIVE CONTROL SIDESTICKS

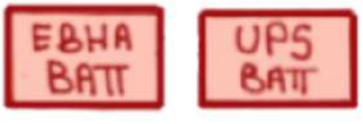


- FLIGHT CONTROL COMPUTERS

- BACKUP FLIGHT CONTROL UNIT

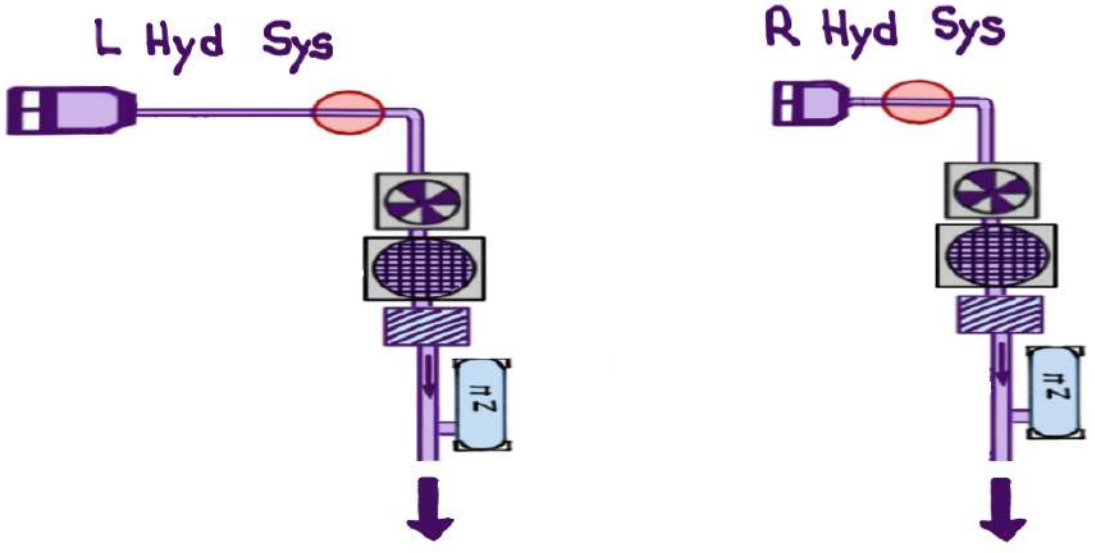
- REMOTE ELECTRONIC UNITS

- FLIGHT CONTROL BATTERIES



Hydraulically - actuated

- Hydraulic sources

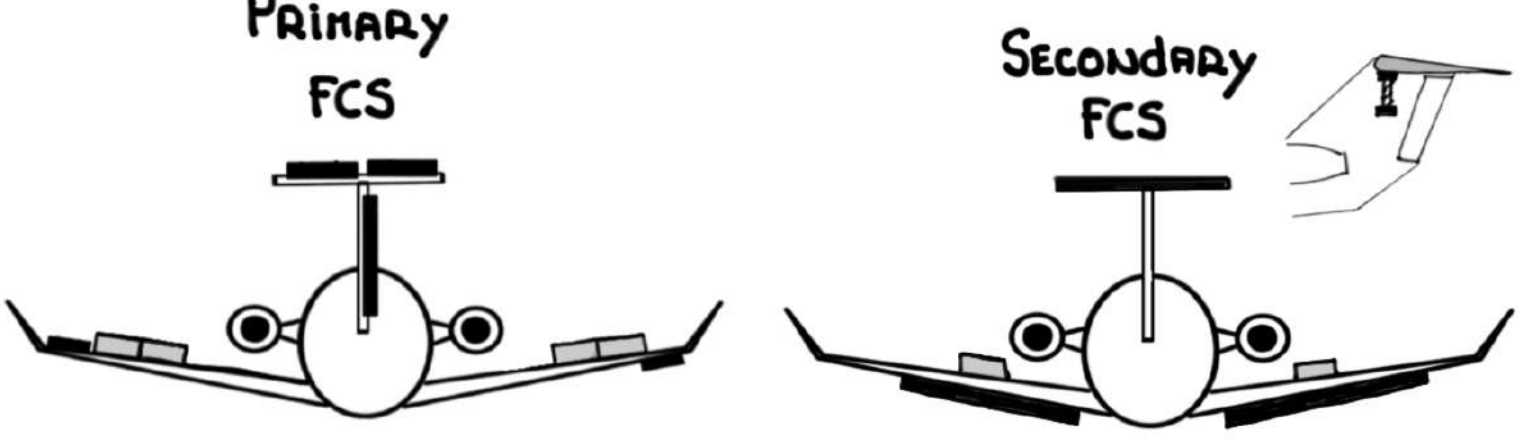


- Electro-Hydraulic Servo Actuator

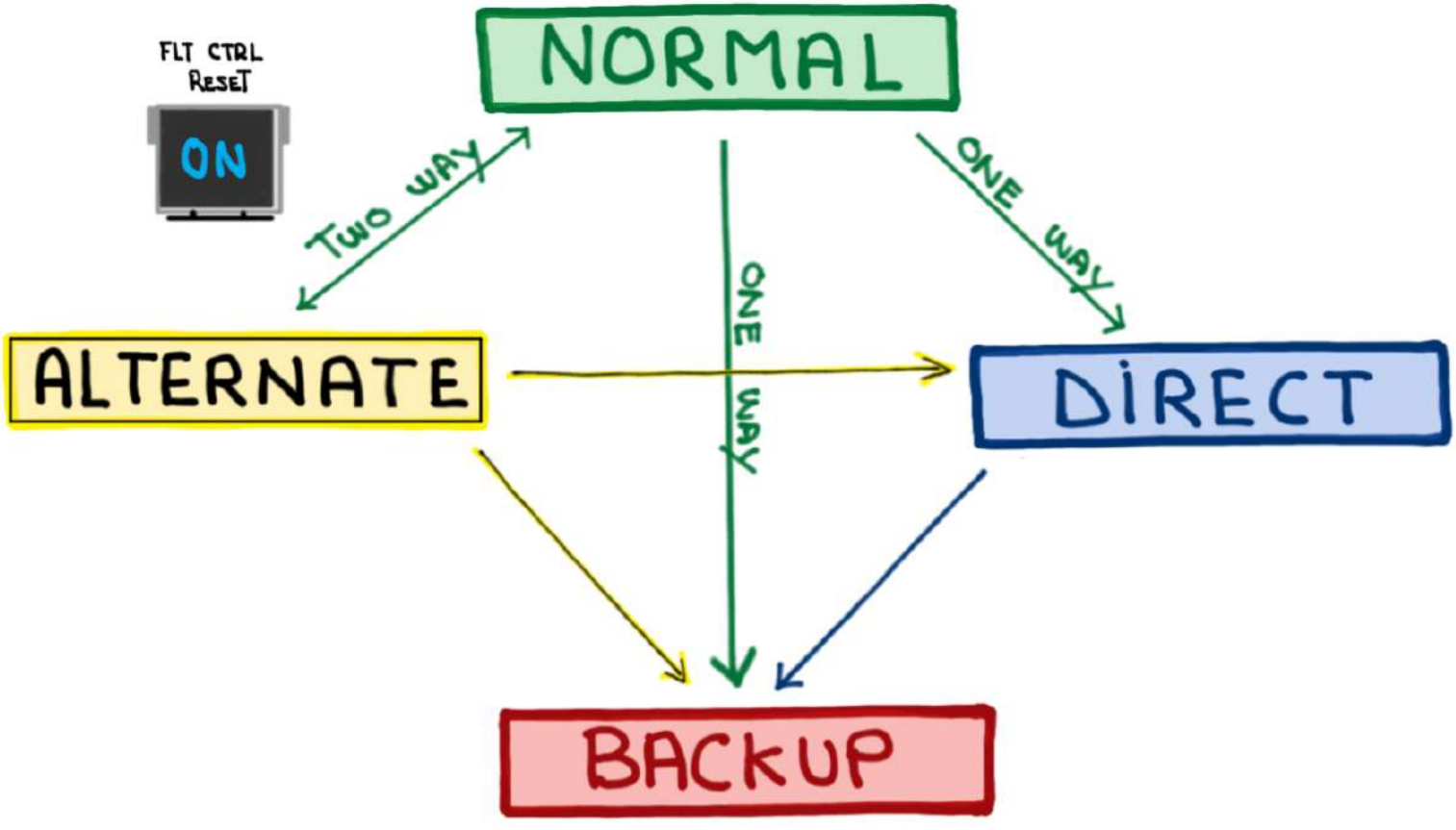
(9) EHSA

- Electrical Backup Hydraulic Actuator

(7) EBHA



FLIGHT CONTROL LAW MODES



NORMAL

FCC 1	
Ch A	Ch B

FCC 2	
Ch A	Ch B

Minimum requirements:

① One (1) IRU + One (1) AHRS

OR

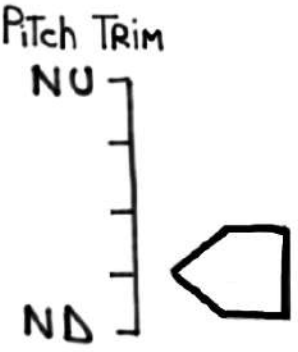
Two (2) IRUs

② Two (2) ADS

- Gain and control deflection scheduled with airspeed
  - Amplification of signal to achieve desired aircraft response
  - Lower gain - less control deflection and vice versa
- High authority Yaw Damper
- Sub-modes: On Ground, In flight, AOA Limiting, and High Speed Protection

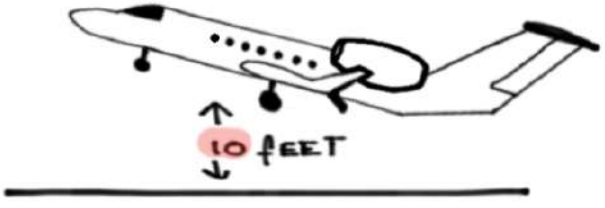
NORMAL Sub-modes:

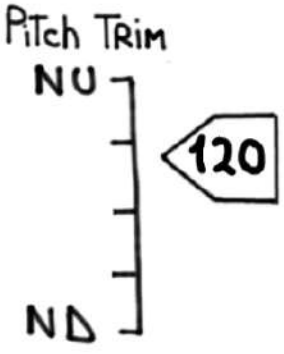
InflighT – AP ON



- WhiTe TRiangle only
- No digiTs

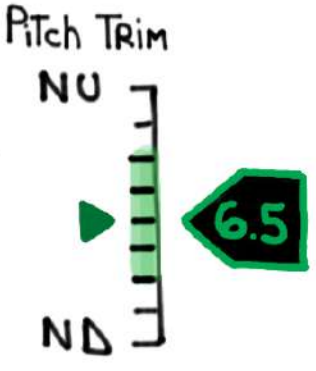
InflighT – AP OFF





- AcTive AT 10' AGL
- Displays TRIMMED KCAS
- Scale: 60 KCAS INCREMENTS

ON GROUND



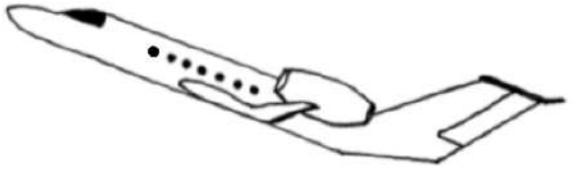
- GREEN BAND
- STab posiTion in degREES NOSE Up / DOWN
- COMMANDS HORIZONTAL STABILIZER
- < 10' AGL

AOA Limiting:

- 0.75 AOA - Pitch Limit Indicator (PLI) appears

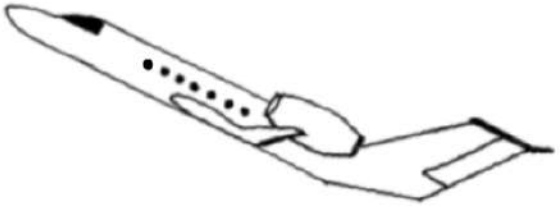
- 0.88 - 0.93 AOA Limiting (based on closure rate)

FCC AOA Limiting



- 0.97 AOA - Stick shaker activates

Stall Protection Active

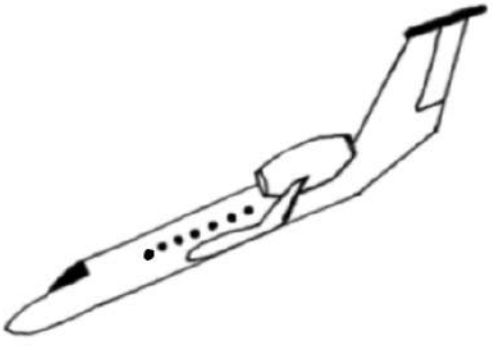


* Even a sustained full aft sidestick deflection will not cause the aircraft to stall

High Speed Protection:

- Available when:
  - autopilot is OFF
  - Vmo / Mmo + 5 (depending on acceleration rate)
- Pitch control restricted by the FCS
- Helps prevent an overspeed condition by decreasing pitch nose down authority 75%

High Speed Protect Active

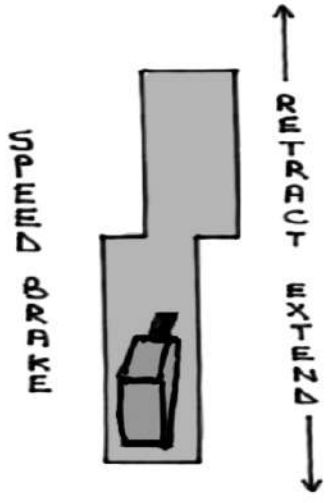


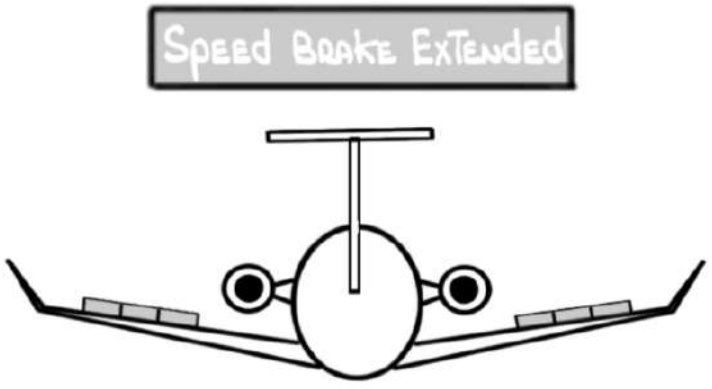
- Protection inhibited with autopilot ON or at a high bank angle (protection fades out > 60° bank)
- Does not prevent exceeding Vmo/Mmo

- Additional functions and features:

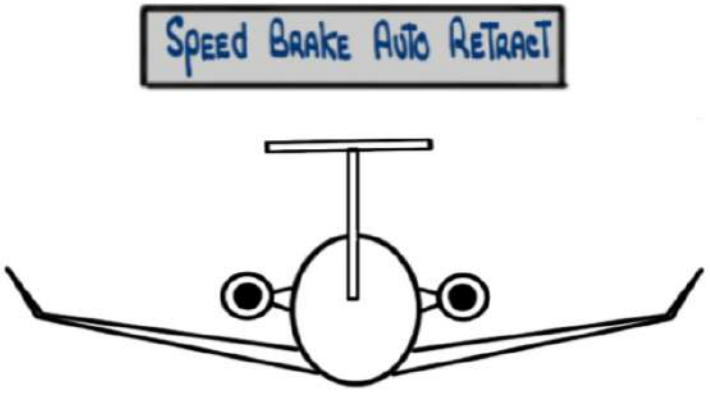
Speedbrake - Auto Retract:

Stuck or jammed Speed Brake handle





90% Throttle Resolver Angle (TRA)



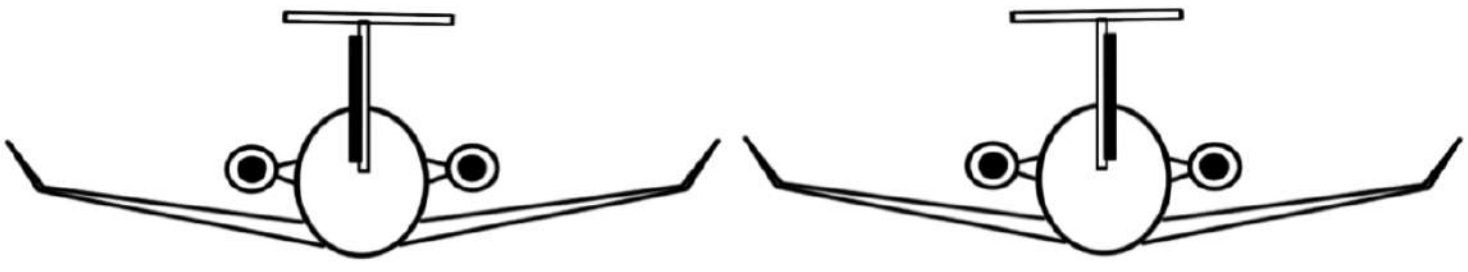
Speed brakes retract but speed brake handle does not

Dynamic Rudder Limiting:

Helps prevent a pilot from overstressing the rudder

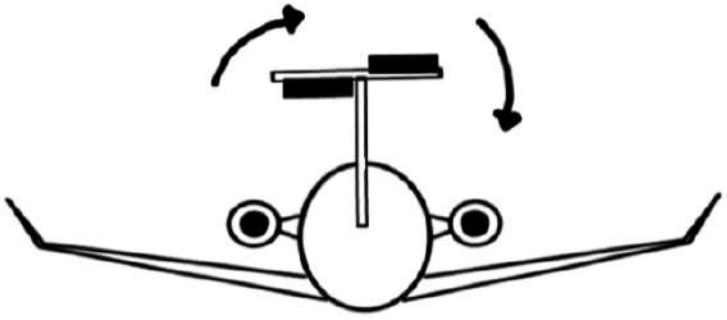
Low speed: High deflection (25°)

High speed: Low deflection (3.6°)



Elevator Split Load Limiting:

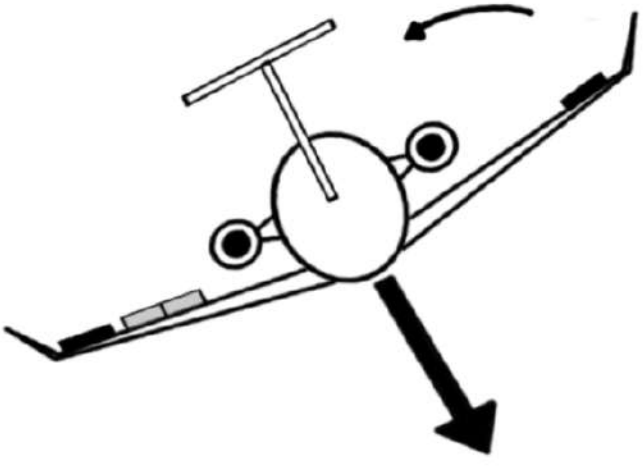
Protects against large torque associated with a split elevator



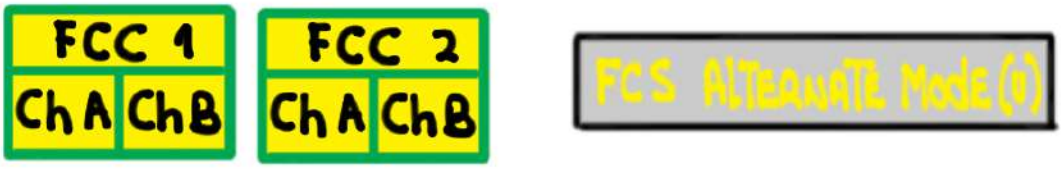
Maneuver Load Alleviation:

Ailerons symmetrically deflect upwards to reduce loads when the pilot commands > 1.5 Gs

Reaches Maximum 3° deflection ≥ 2.5 Gs



ALTERNATE



① < Two (2) ADS

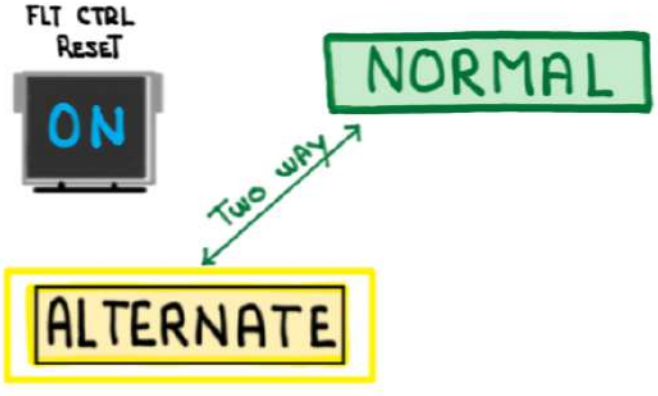
② < Two (2) IRUs

OR

< One (1) IRU + One (1) AHRS

③ Loss of communication between FCCs and HSTS

- <u>Hardware</u> malfunction
- Probability of occurrance: < 1 per 10 million flight hours

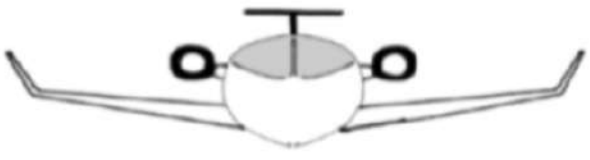


- FLT CTRL Reset switch may allow return to NORMAL if the reason for degrade is resolved

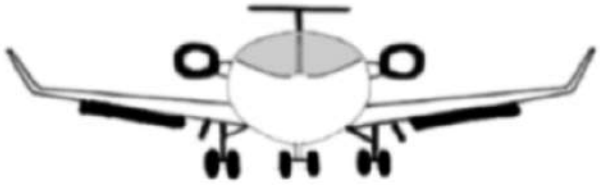
- Simplified yaw damper (more oscillations expected)
- Speed brakes (auto retract not available)
- Stick shaker earlier onset (0.85 AOA)
- Loss of the following features:
  - Autopilot (AP)
  - AP Disc/TSS button (TSS not available)
  - AOA Limiting
  - High speed protection
  - Turn coordination
  - Dynamic Rudder Limiting
  - Maneuver Load Alleviation
  - Steep Approach
- Sidesticks
  - Remain Linked
  - May revert to Degraded Active Mode

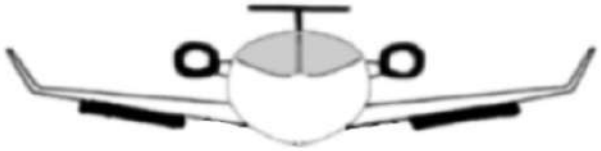
- MAY LOSE THE following FEATURES DEPENDING ON CAUSE of MODE CHANGE
  - NORMALIZED AOA (STick shaker / PLI)
  - LOW SPEED WARNING
  - PRIMARY PITCH TRIM SWITCH ON SIDESTICK if
    - STAB PRI TRIM FAIL (U)
    - UTILIZE PEDESTAL PITCH TRIM SWITCH INSTEAD
- TWO (2) fixed SPEED (GAINS) SCHEDULES:
  - High SPEED: 340 KTS (LOW GAIN)
  - LOW SPEED: 250 KTS (High GAIN)

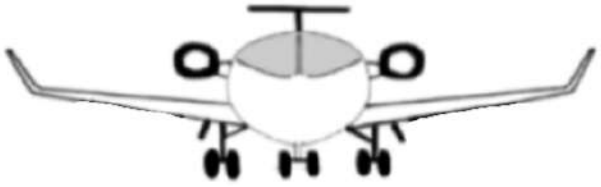
THE SPEEDS ARE DEPENDENT ON FLAP OR LANDING GEAR POSITION



High Speed schedule / LOW GAIN





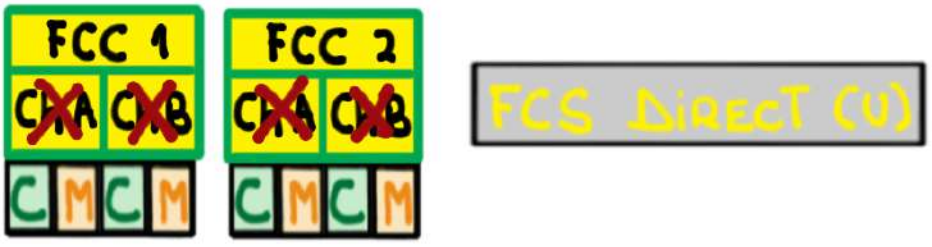


Low Speed schedule / high gain

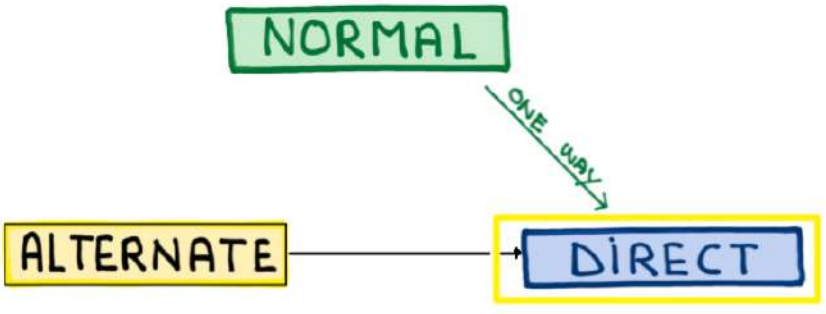
Extend flaps to at least 10° < 200 kts

This improves response due to higher gain at lower speeds

DIRECT



- All FCC channels are invalid
- Command C and Monitor M lanes do not agree

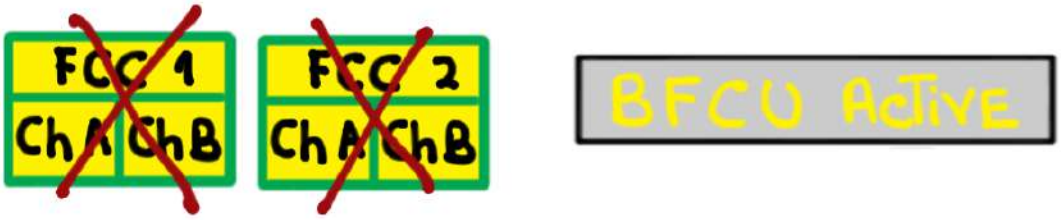


- Software malfunction
- Return to NORMAL or ALTERNATE not possible
- Flying qualities are identical to ALTERNATE except that:
  - Sidesticks → Degraded Active Mode
  - Primary pitch trim switches unavailable

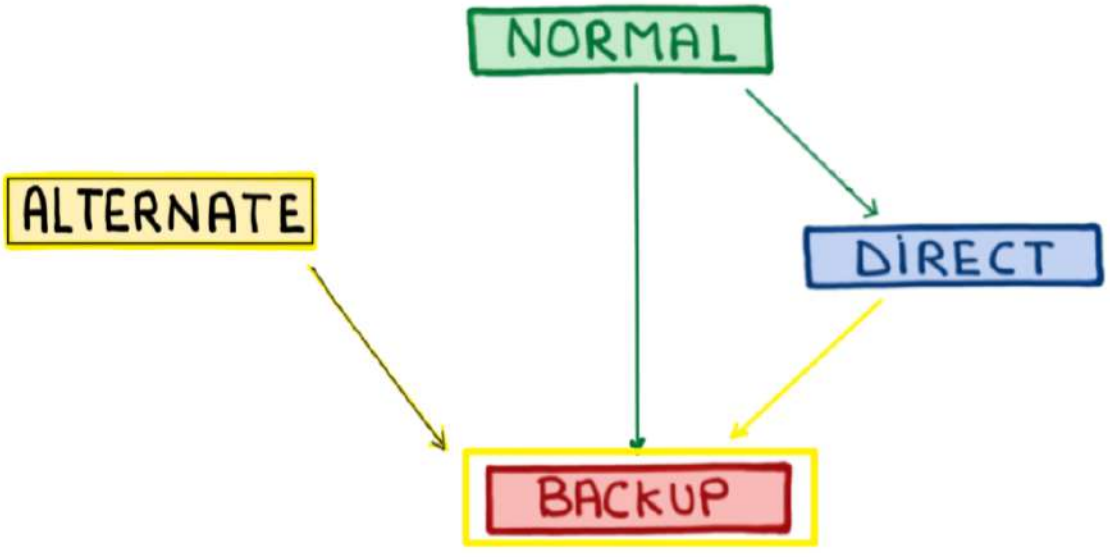
- Two (2) fixed speed (gains) schedules:
  - High speed: 340 kts (Low gain)
  - Low speed: 250 kts (High gain)

- Loss of additional features:
  - Normalized AOA
  - Stick Shaker
  - PLI
  - Low Speed Warning
  - Auto Ground Spoilers
  - Roll Trim
  - AP Disc/TSS button (will not stop yaw trim movement)

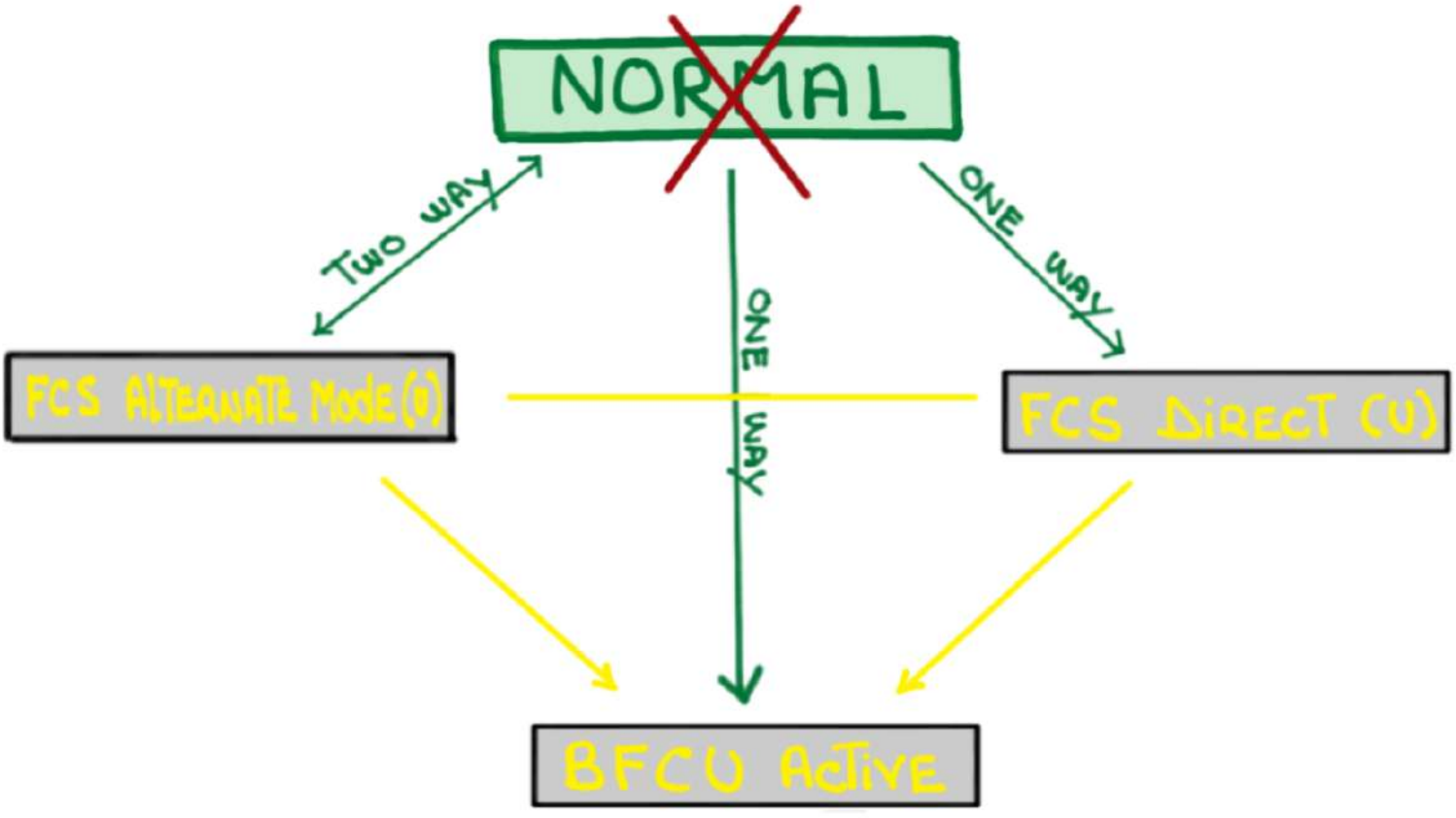
BACKUP



- All FCC channels cannot compute Control Laws
- **BFCU** and its own Control Laws provides Get Home capability



- **BFCU** communicates directly with **EBHA** actuators
- Probability of occurrence < 1 in a billion flight hours



ANY FLIGHT CONTROL LAW OTHER THAN NORMAL:

FCS ALTERNATE MODE (A)

FCS DIRECT (D)

BFCU ACTIVE

① TAKEOFF IS PROHIBITED

② MAXIMUM SPEED: 285 KCAS/M0.90

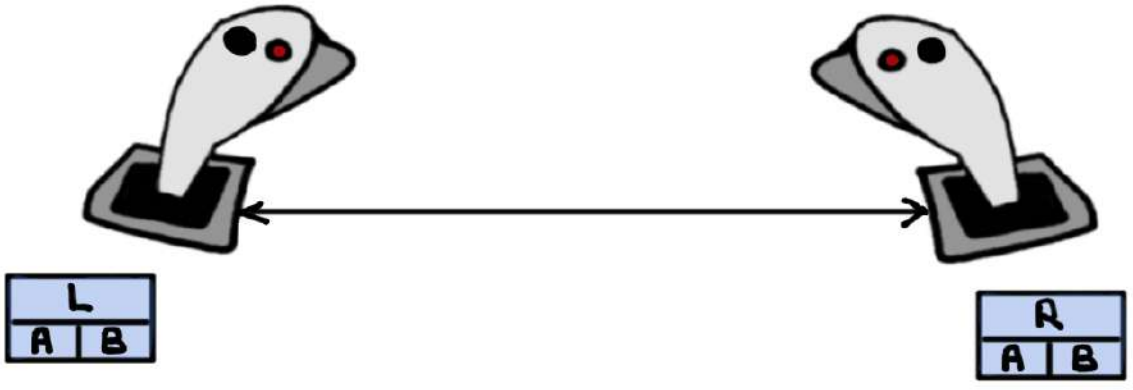
③ FLIGHT INTO KNOWN ICING CONDITIONS PROHIBITED. IF IN ICING CONDITIONS EXIT ICING CONDITIONS

④ MAXIMUM LANDING CROSSWIND: 10 KNOTS

⑤ VREF + 10 MINIMUM

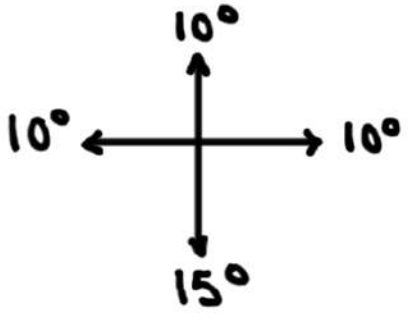
Active Control Sidesticks (ACS)

- Each ACS contains a computer with Two (2) channels one active and the other on standby



- Sidesticks are linked to each other. Input on one sidestick results in the same motion on the other

- Range of motion:



- Three (3) operational Modes:
  1. Active
  2. Degraded Active
  3. Passive - Internal Failure

① Active Mode:

- Feedback enhances situational awareness
- Control surface loading provides Electronic-Feel
- Inputs seen on both ACSs

② Degraded Active:

Sidestick Degraded Actv

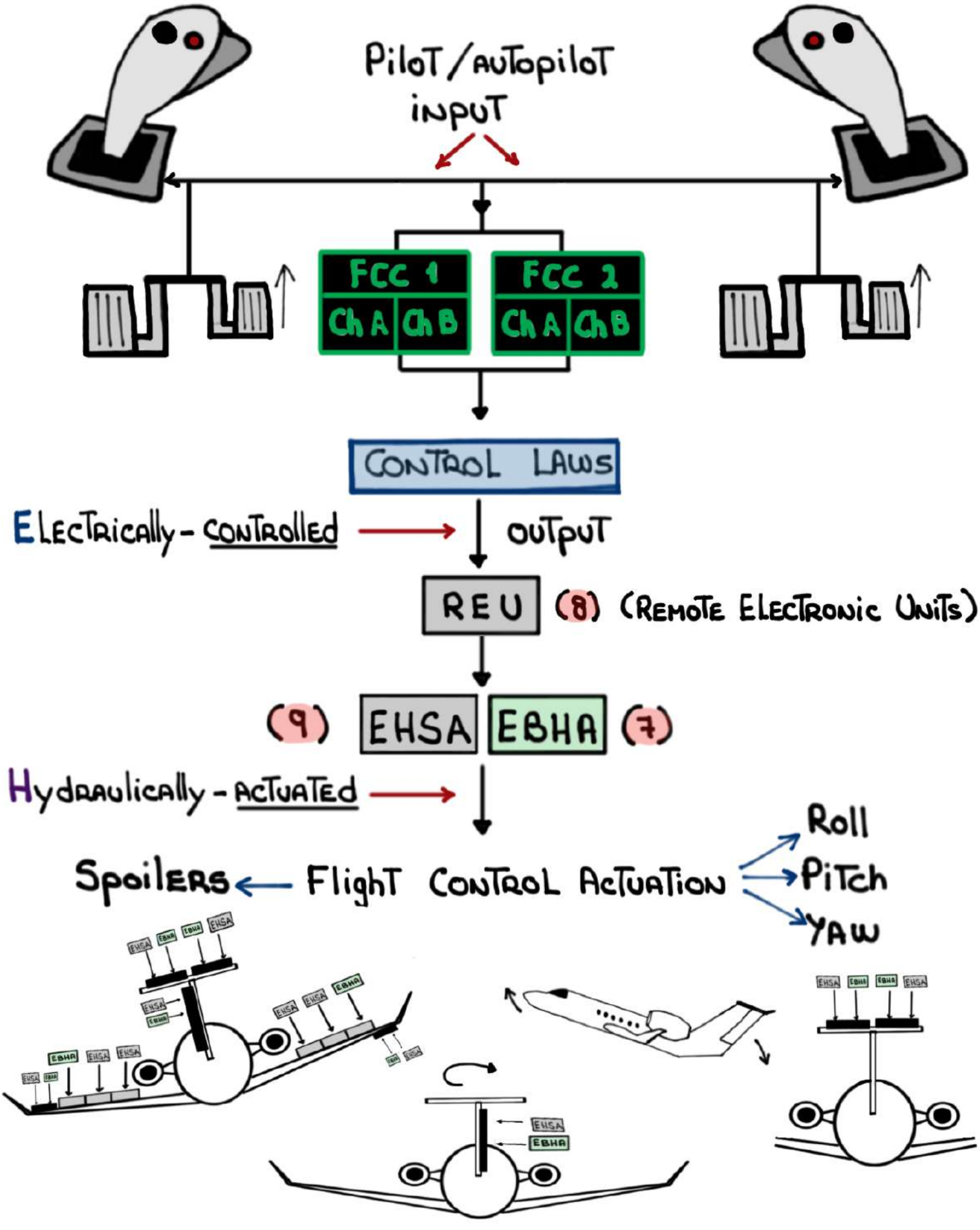
- Submode of Active

  STill considered Active because Linking of the ACSs remains operative
- Degraded Electronic Feel

③ Passive - Internal Failure:

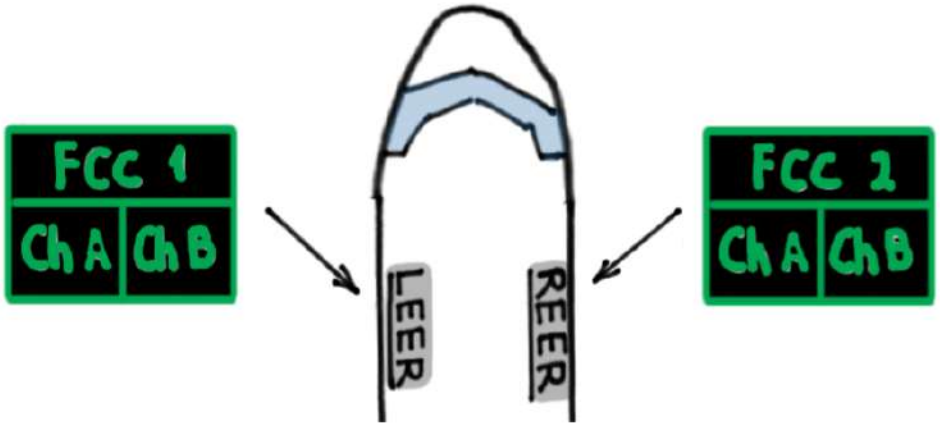
- Internal failure
- Loss of cross-Linking

L Sidestick Passive (U)


Pilot/autopilot input
FCC 1
Ch A
Ch B
FCC 2
Ch A
Ch B
Control Laws
Electrically-controlled
output
REU (8) (Remote Electronic Units)
(9) EHSA EBHA (7)
Hydraulically-actuated
Spoilers
Flight Control Actuation
Roll
Pitch
Yaw
EHSA
EBHA

Flight Control Computers (FCCs)

- Brains of the FCS
- Located in the **LEER** and **REER**



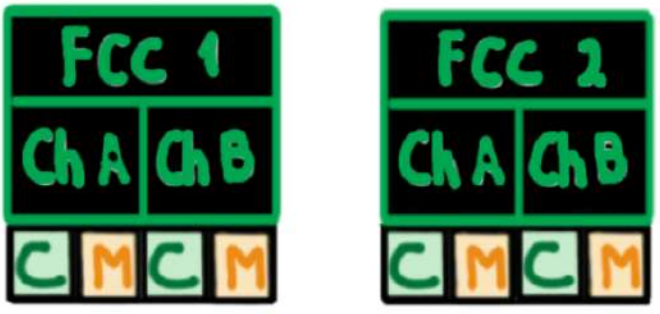
- Convert input from the crew/autopilot to an electrical output
- Provide a command to the Hydraulic Actuators which move the flight control surfaces to the requested position
- Each FCC has Two (2) channels for a Total of four (4) channels
- This configuration provides four (4) redundant, dissimilar, and independent channels of operation

- A single FCC channel CAN OPERATE the flight controls

- Each FCC channel has Two (2) lanes:

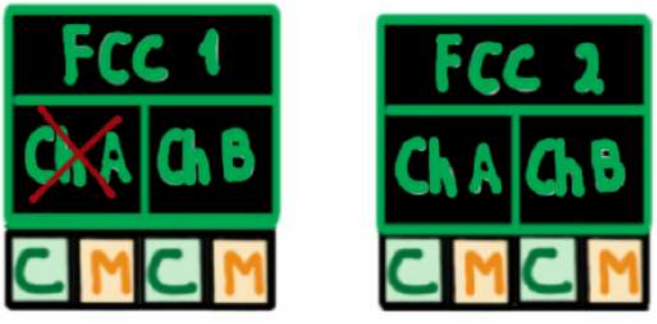
  ① A Command [C] lane, and

  ② A Monitor [M] lane

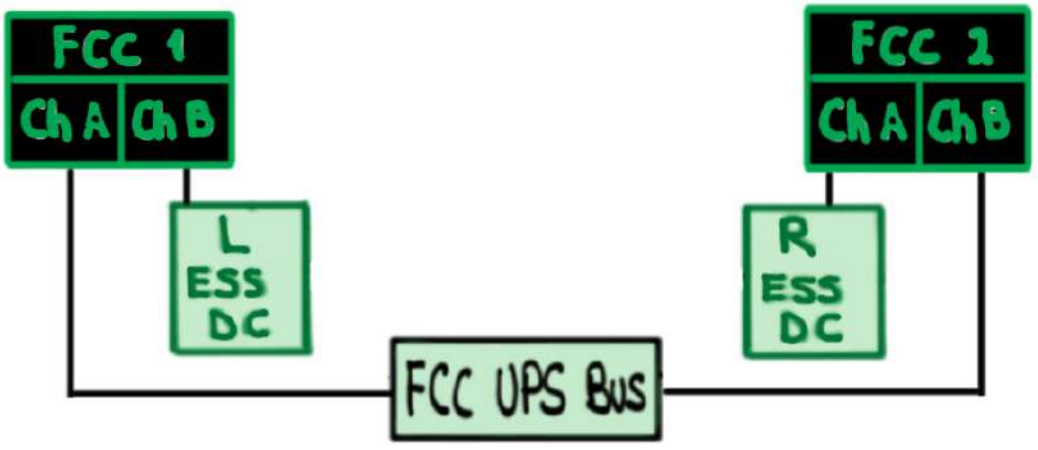


- Their purpose is to provide system integrity by computing input using different software and having to come up with the same output

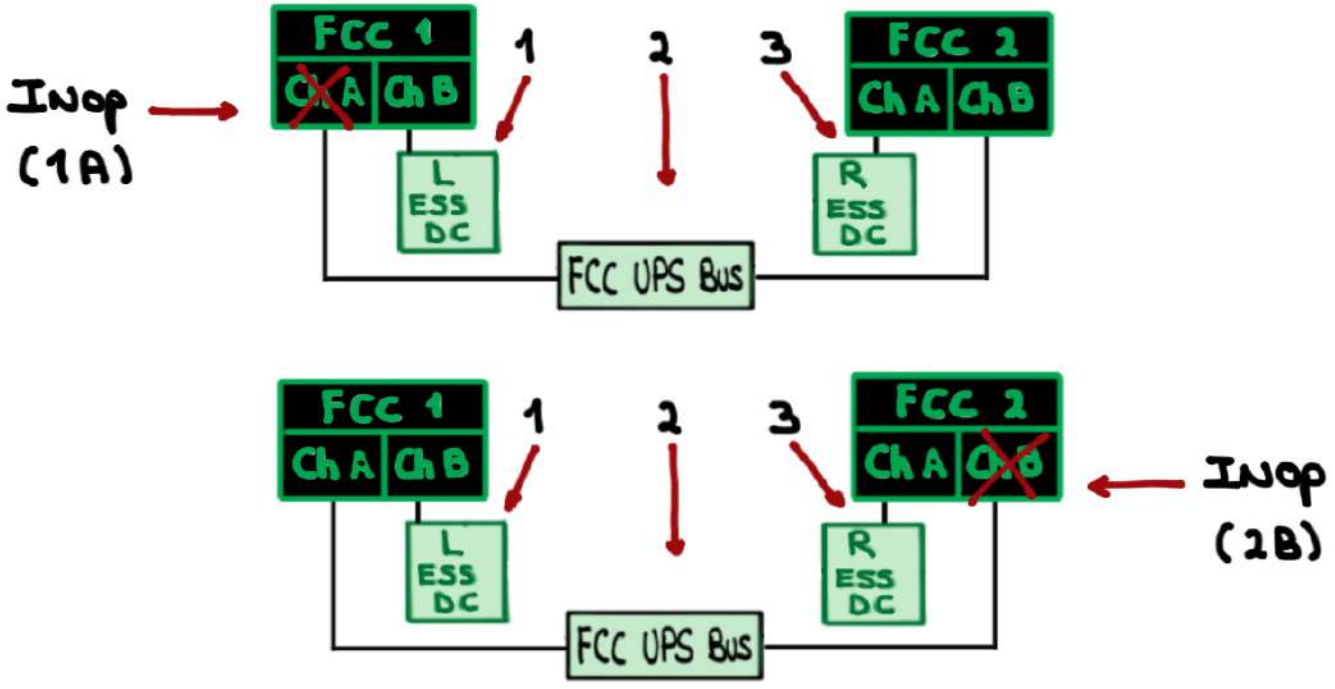
- Any significant difference between a [C] and a [M] lane causes that channel to fail



- Power Sources:

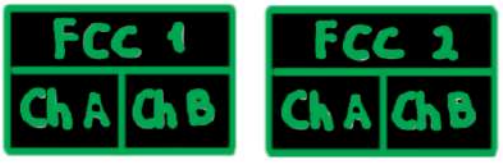


- Three (3) separate power sources <u>required</u>.
- Dispatch with one (1) FCC channel inoperative is possible under the MMEL provided the remaing three (3) channels are powered by three (3) separate power sources

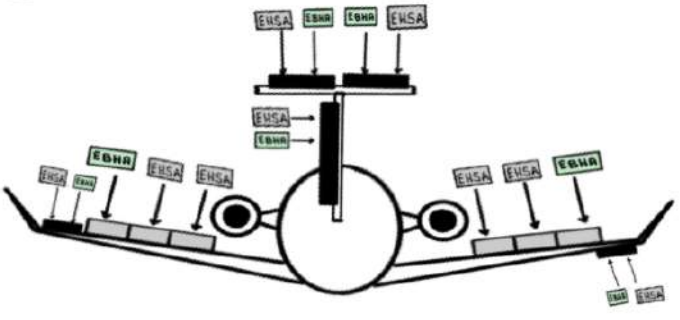


– FLIGHT CONTROL RESET switch

- LOCATED ON CENTER PEDESTAL
- WHEN PRESSED:
  - RESETS A AND B CHANNELS IN BOTH FCCs



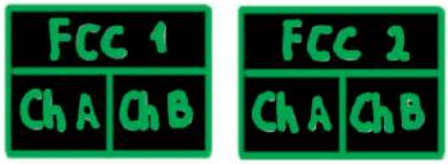
  - RESETS ALL SIXTEEN (16) FLIGHT CONTROL SURFACE ACTUATORS



- USED WHEN DIRECTED BY A CHECKLIST
- DOES NOT WORK IN:

FCS DIRECT (U)

BFCU ACTIVE

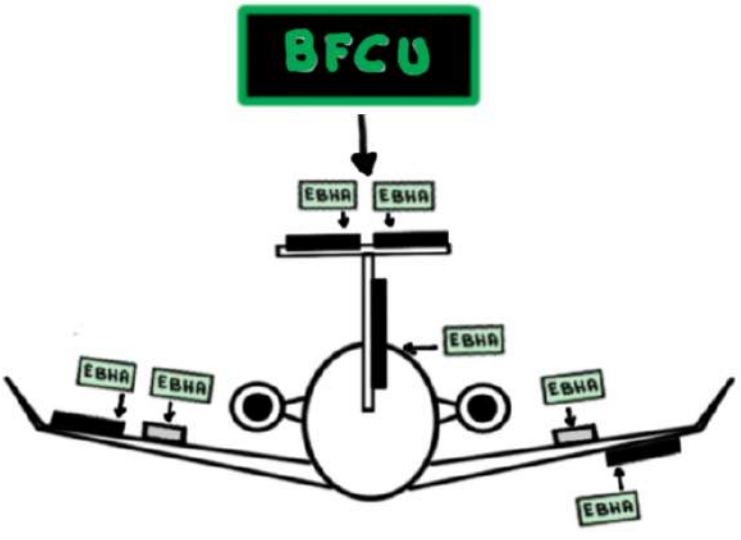


CONTAIN SOFTWARE CALLED CONTROL LAWS OR CLAWS. ITS PURPOSE IS:

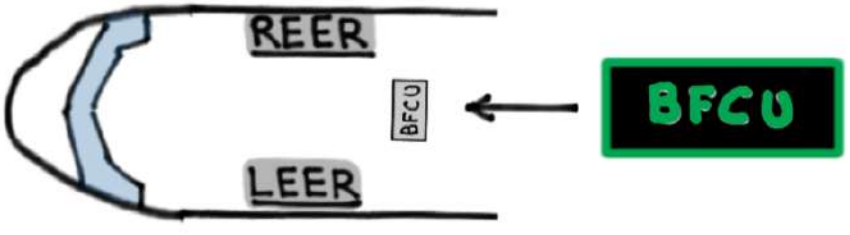
- MAKE THE AIRCRAFT FLY LIKE A GULFSTREAM
- DAMPEN UNDESIRABLE AIRCRAFT MOTIONS SUCH AS DUTCH ROLL
- IMPLEMENT SEVERAL PROTECTIVE FEATURES

Backup Flight Control Unit (BFCU)

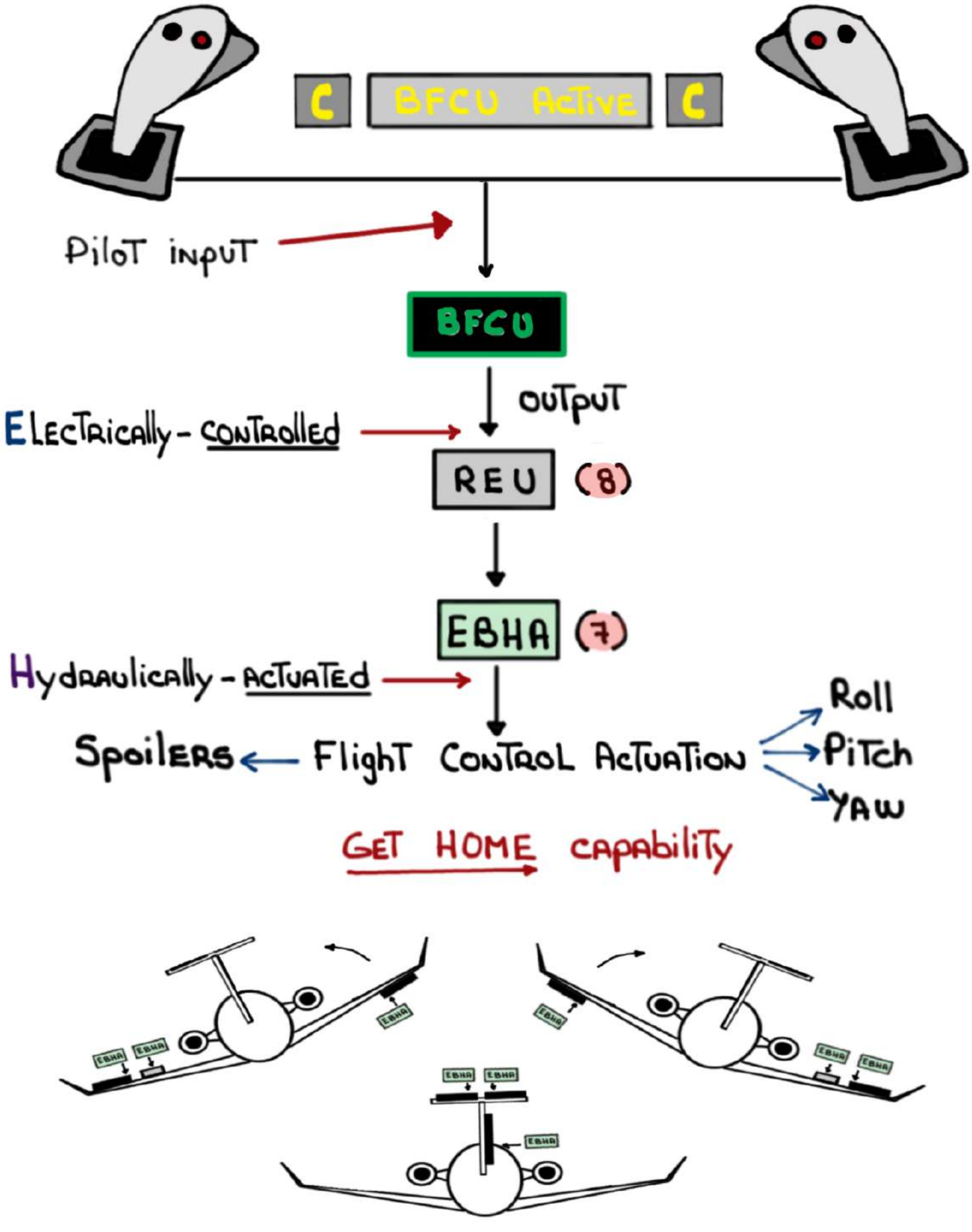
- Designed To provide a GET HOME capability if both FCCs should fail



- The **BFCU** is located under The floor and can be deferred as per The MEL

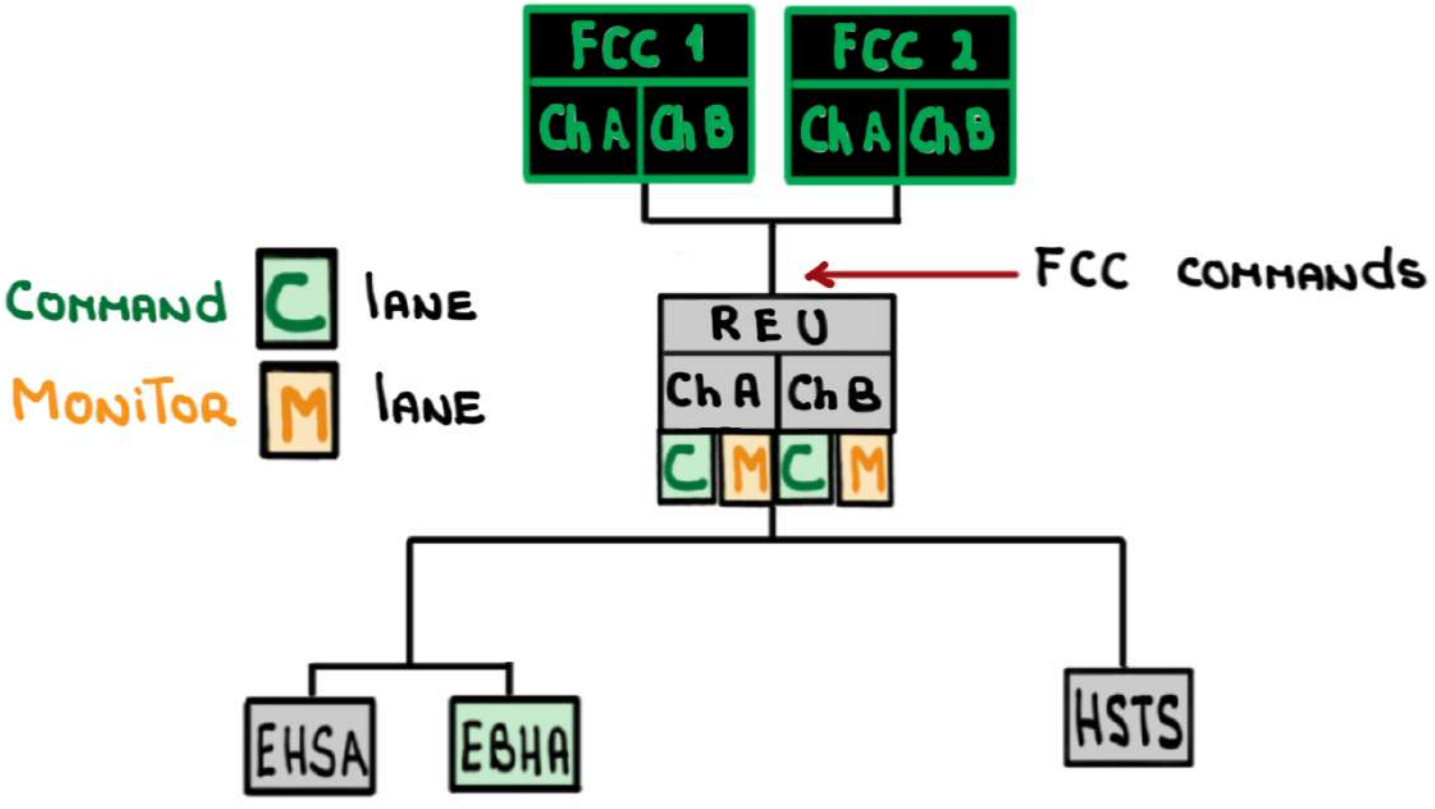


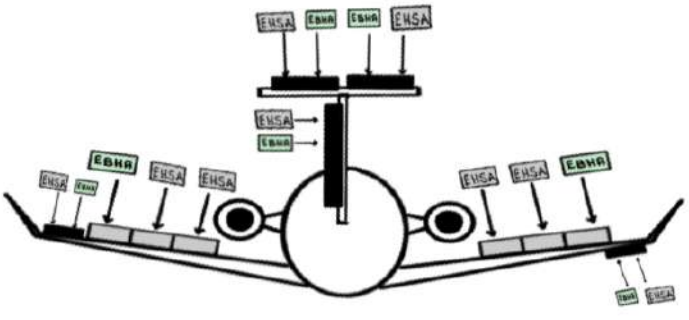
- Once active it cannot be reset in flight
- Inop < 47 knots
- Powered by FCC UPS Bus

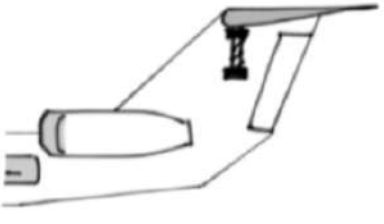

C
BFCU Active
C
Pilot input
BFCU
output
Electrically-controlled
REU (8)
EBHA (7)
Hydraulically-actuated
Spoilers
Flight Control Actuation
Roll
Pitch
Yaw
GET HOME capability
EBHA

Remote Electronic Units (REU)

- There are eight (8) REUs
- The REUs control the Hydraulic actuators EHSA EBHA and Horizontal Stabilizer Trim System HSTS based on FCC commands





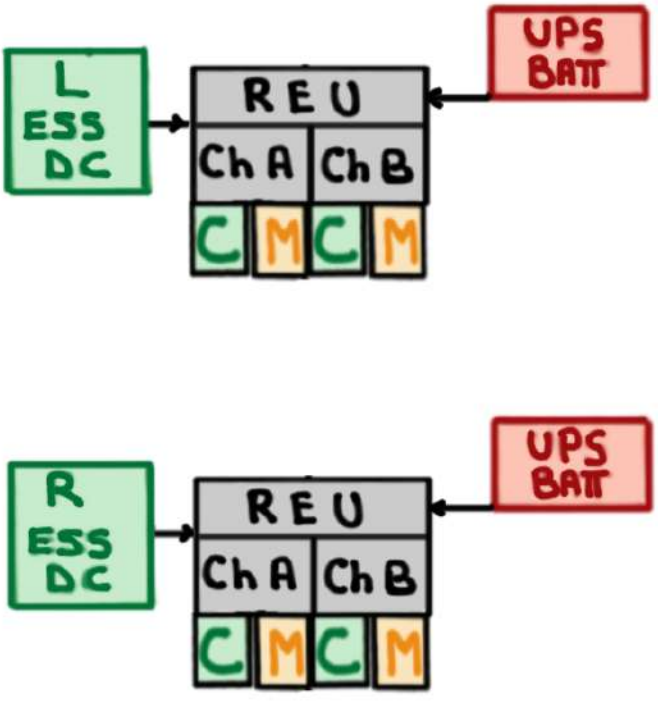


- The REUs are located in multiple locations:

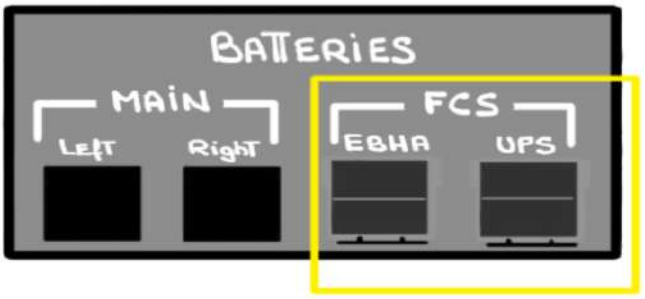
  - Wings (4)
  - Tail (3)
  - Main gear well (1)

  > Eight (8)

- Each REU has Two (2) DC power sources:



FLIGHT CONTROL BATTERIES



THERE ARE TWO (2) FLIGHT CONTROL SYSTEM (FCS) BATTERIES:

① ELECTRICAL BACKUP HYDRAULIC ACTUATOR (EBHA) BATTERY

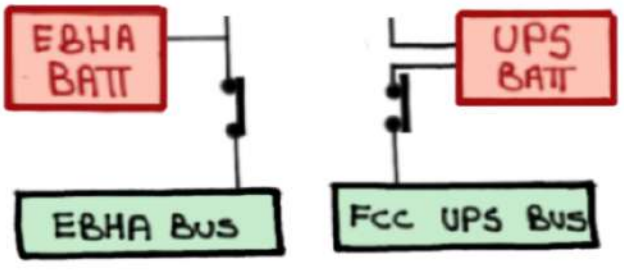
② UNINTERRUPTIBLE POWER SUPPLY (UPS) BATTERY

THE FCS BATTERIES CAN POWER THE FLIGHT CONTROLS FOR THIRTY (30) MINUTES

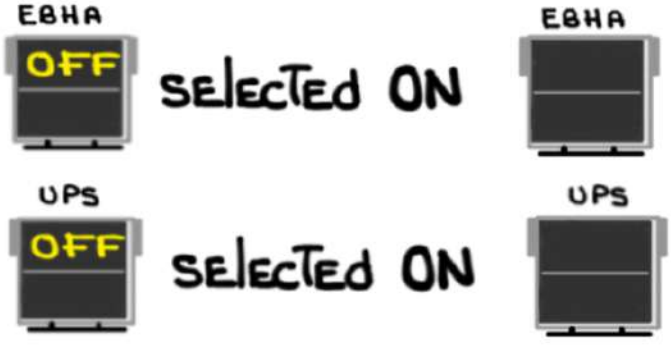
- ILLUMINATED 

IF NO 

POWER IS BEING PRODUCED AND THEY POWER THEIR OWN BUSES (discharging)

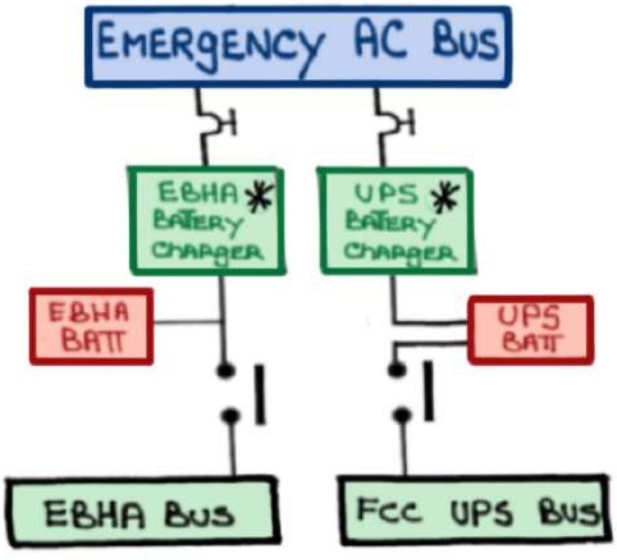


- System Power ON Self Test (SPOST)

- 

- Forty five (45) second test
- No electrical interruptions during SPOST or a complete power down is required

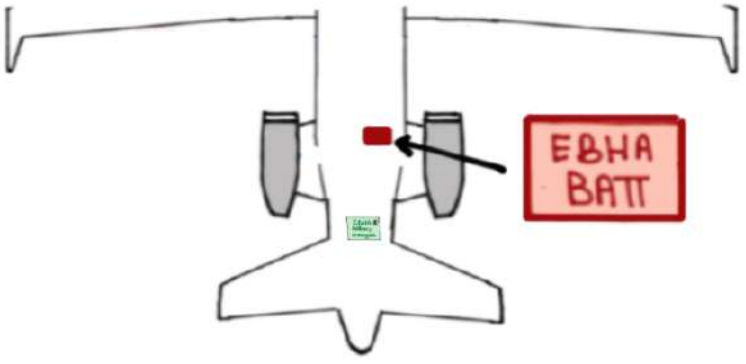
- FCS Batteries - Charger/Transformer Rectifier



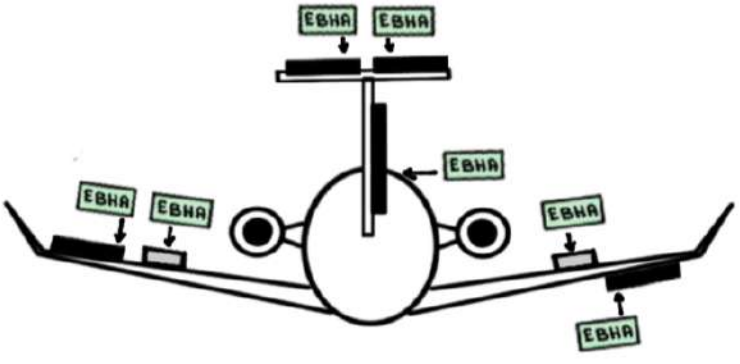
* Dual function: Charger and TR

- EBHA BATT **Electrical Backup Hydraulic Actuator**

  - Nicad, 25 Volts, 53 amp/hour
  - Located in the tail compartment



  - Powers seven (7) EBHA actuators



  - Can be charged by RAT GEN via the EMERGENCY AC BUS

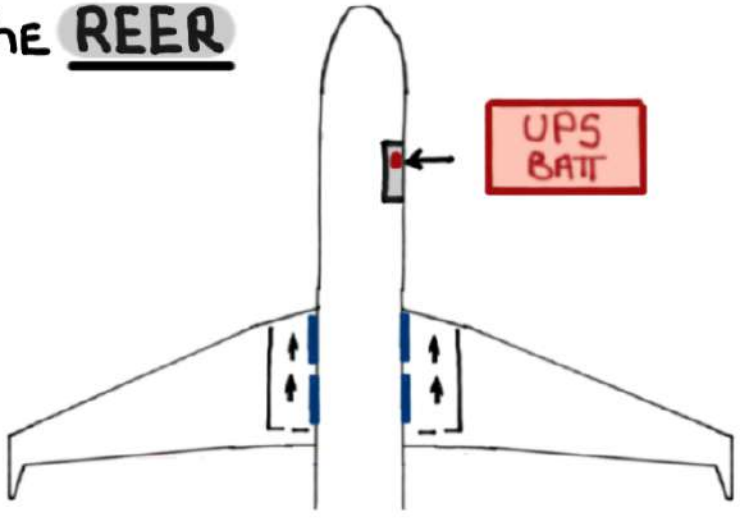
RAT

  - Must be removed from aircraft in cold soaked conditions ($\leq -20°C$) and stored in a location warmer $> -20°C$

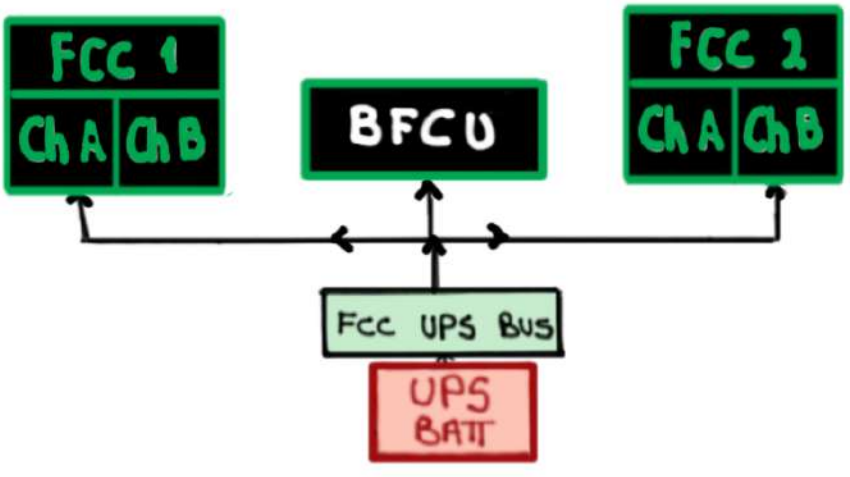
- UPS BATT **UNINTERRUPTIBLE POWER SUPPLY (UPS)**

  - LEAD ACID, 24 VOLTS, 10.5 AMP/HOUR

  - LOCATED IN THE **REER**

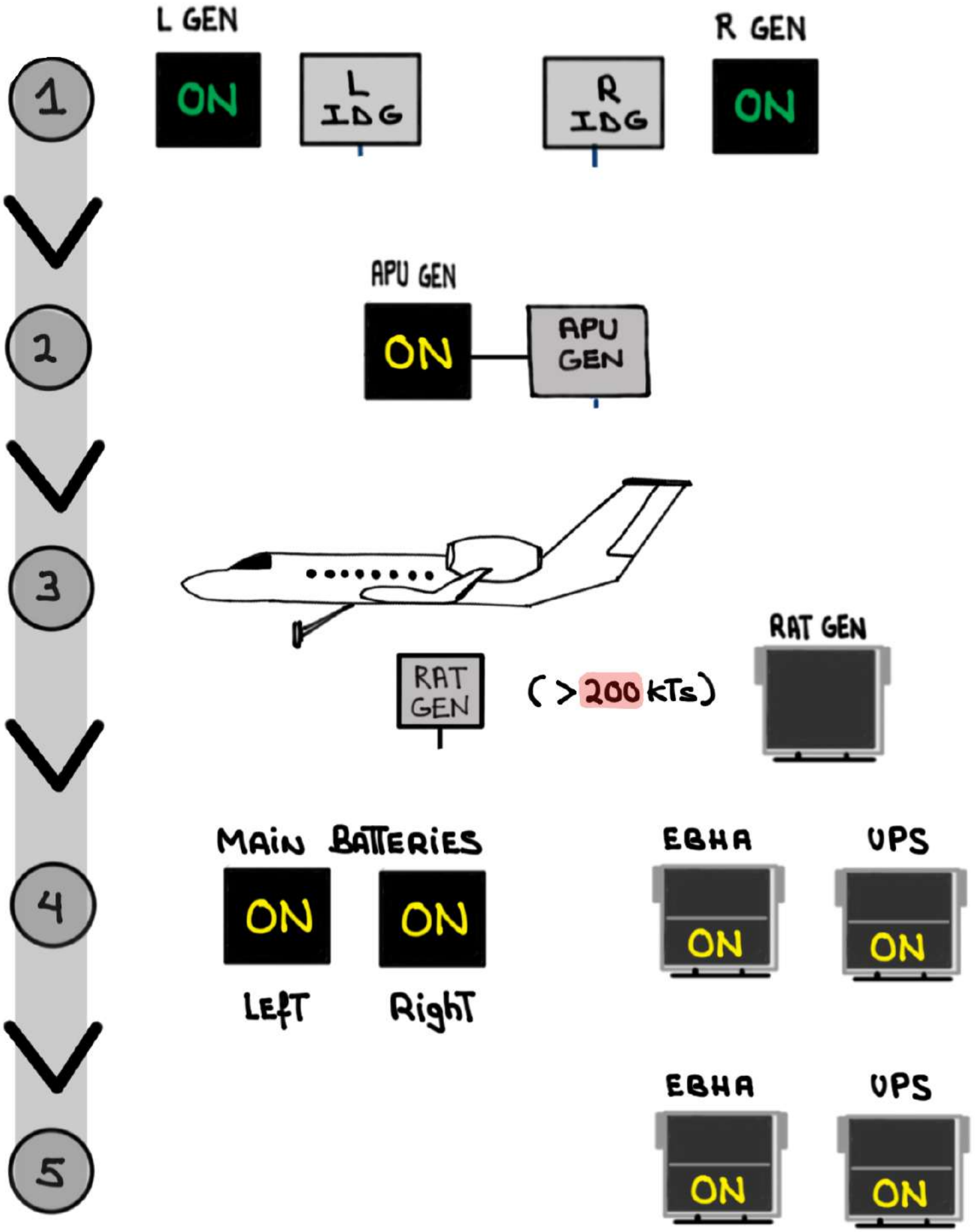


  - POWERS FLIGHT CONTROL COMPUTERS CHANNELS 1A AND 2B

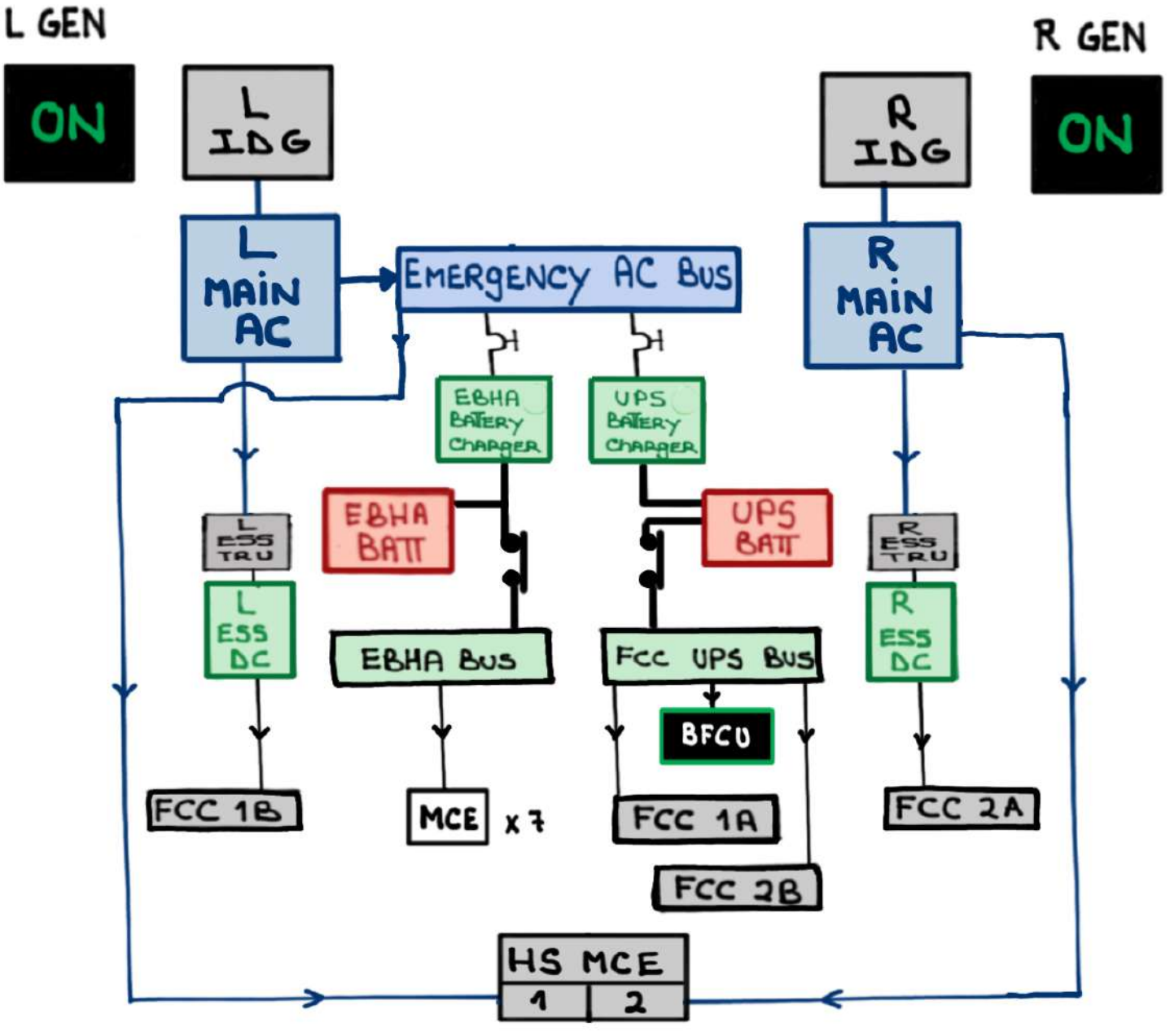


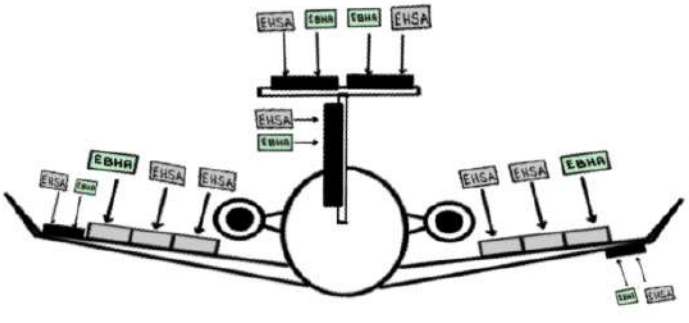
  - SECONDARY POWER SOURCE TO REU

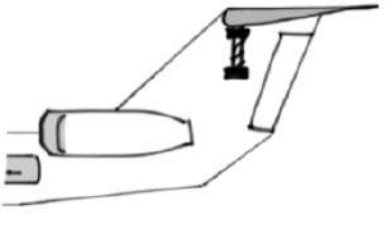
  - CAN BE CHARGED BY RAT GEN  VIA THE EMERGENCY AC BUS


L GEN
ON
L IDG
R IDG
R GEN
ON
1
APU GEN
ON
APU GEN
2
3
RAT GEN
(>200 kTs)
RAT GEN
MAIN BATTERIES
ON
ON
LEFT
RIGHT
4
EBHA
ON
UPS
ON
EBHA
ON
UPS
ON
5

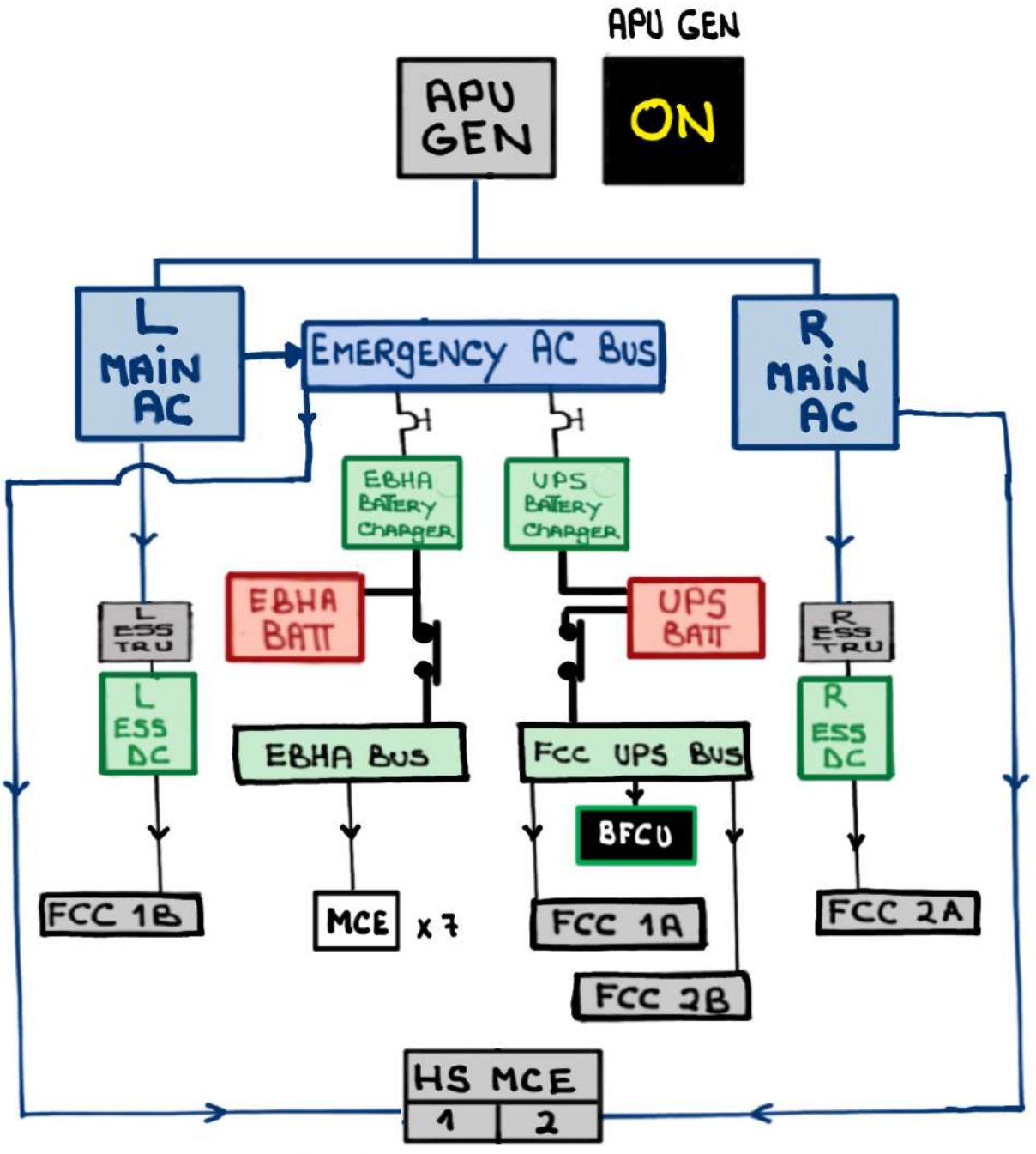
1 Flight Control Law Mode NORMAL

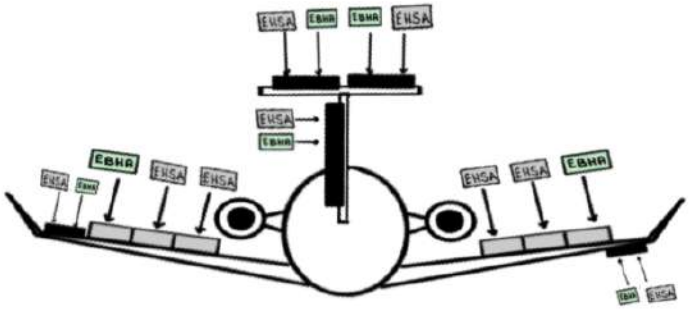


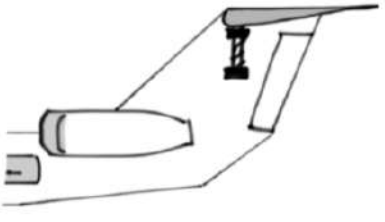




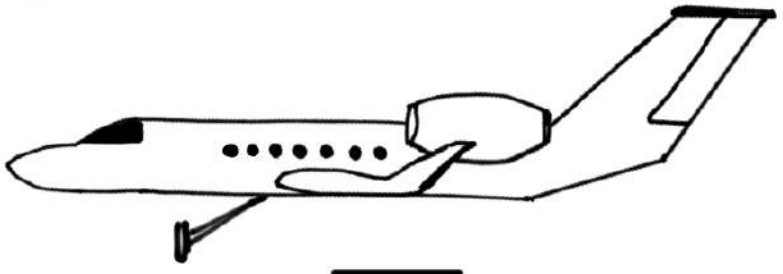
2 FLIGHT CONTROL LAW MODE NORMAL







3 FLIGHT CONTROL LAW MODE NORMAL



RAT GENERATOR ON

RAT GEN (>200 KTS)

EMERGENCY AC BUS

EBHA BATTERY CHARGER

UPS BATTERY CHARGER

L ESS TRU

EBHA BATT

UPS BATT

R ESS TRU

L ESS DC

EBHA BUS

FCC UPS BUS

R ESS DC

BFCU

FCC 1B

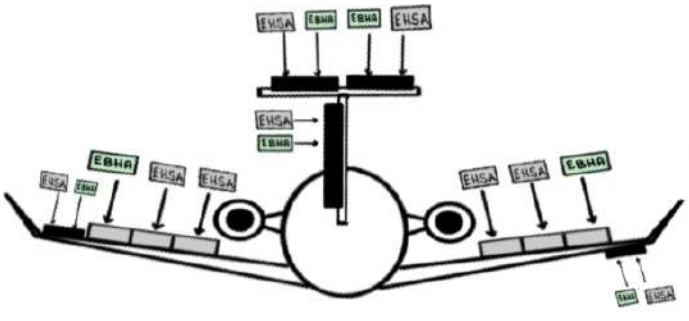
MCE x 7

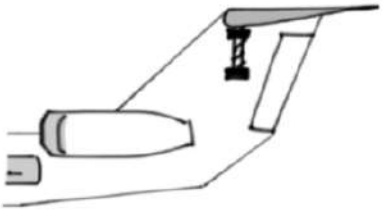
FCC 1A

FCC 2A

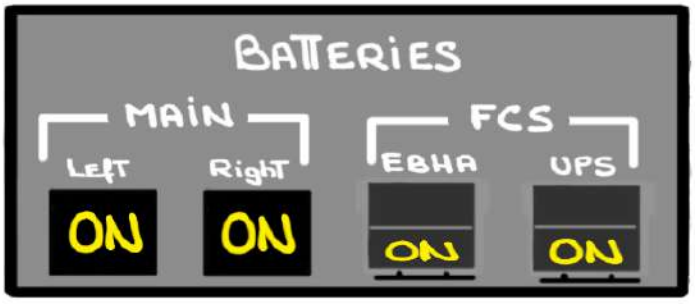
FCC 2B

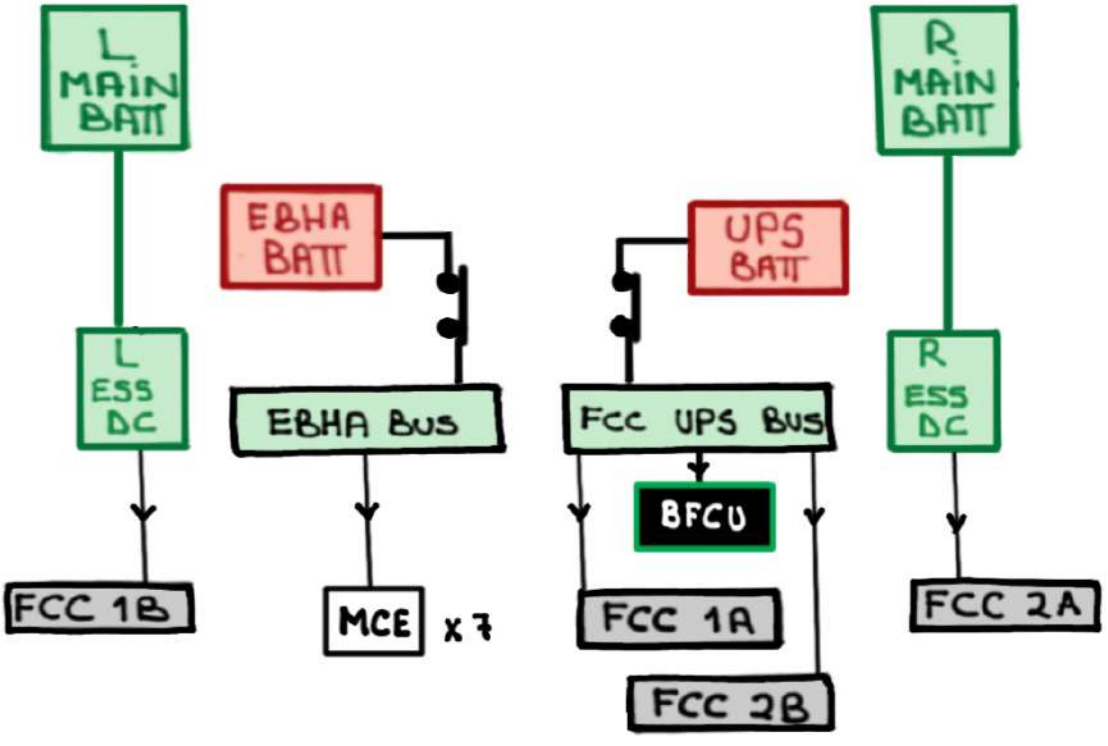
HS MCE 1

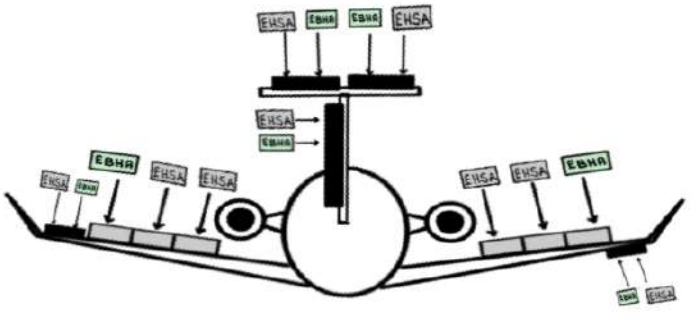




4 FLIGHT CONTROL LAW MODE NORMAL

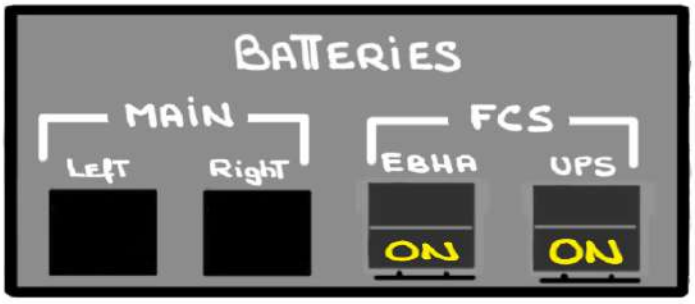


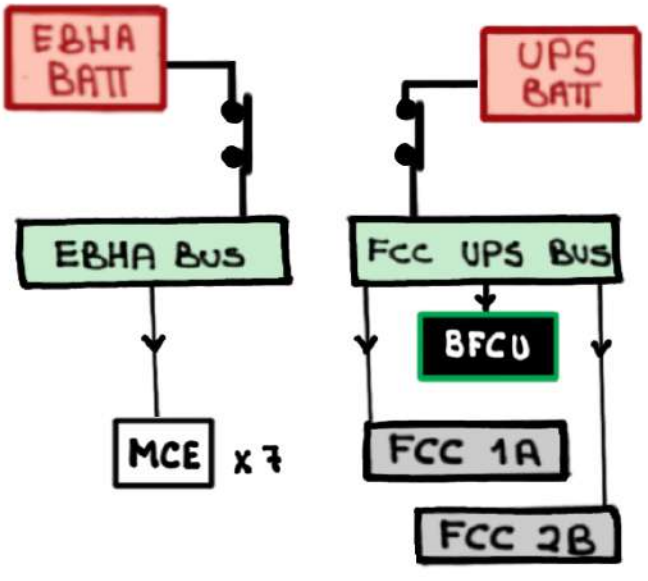


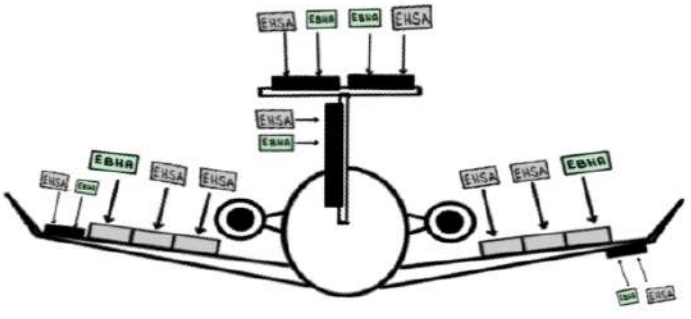


5

FLIGHT CONTROL LAW MODE NORMAL

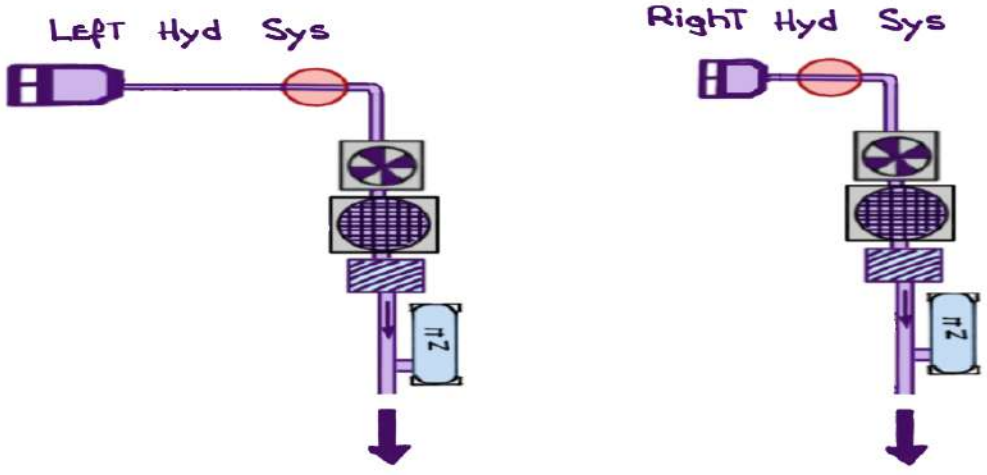






Hydraulic Actuators

- Hydraulic fluid and pressure is provided by:



- There are sixteen (16) Hydraulic Actuators

- Two (2) actuators for each primary flight control surface:

  - Ailerons (4)
  - Elevators (4)
  - Rudder (2)

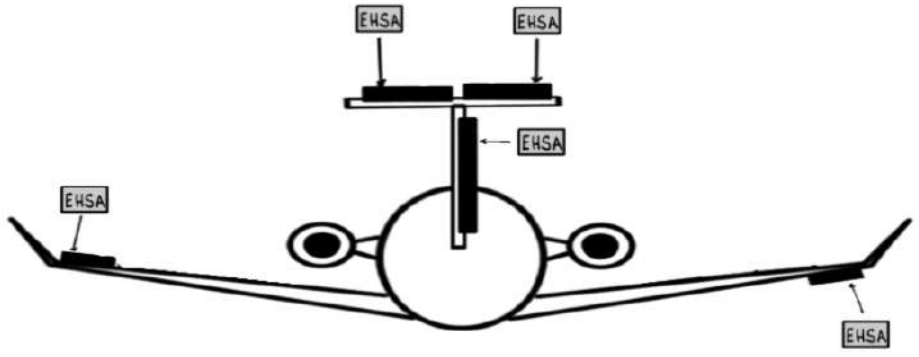
  > Ten (10)

- There is one (1) actuator for each spoiler panel

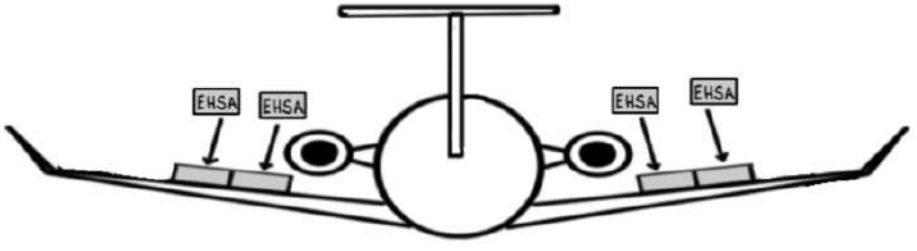
  - Inboard (2)
  - Midboard (2)
  - Outboard (2)

  > Six (6)

- There are Two (2) Types of actuators:
  - Electro-Hydraulic Servo Actuator EHSA
    - One (1) for each primary flight surface

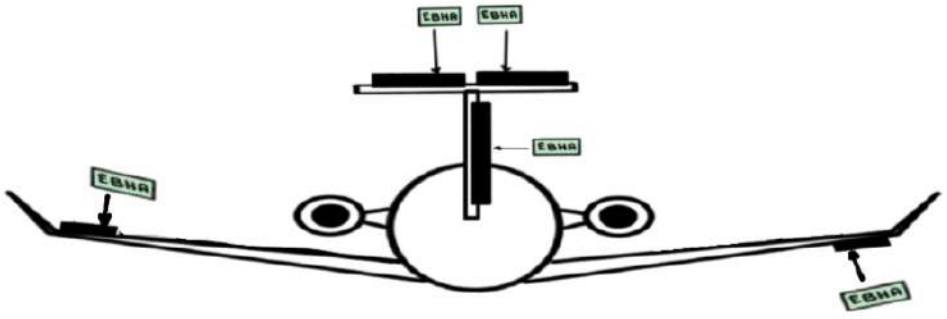


    - One (1) for each inboard and midboard spoiler

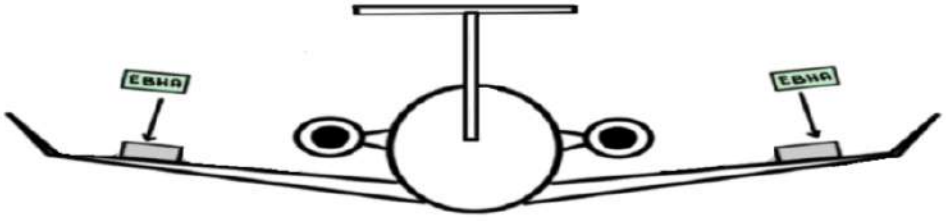


    - Uses Left and Right Hydraulic systems
    - Commanded by an REU → EHSA
    - Two (2) modes:
      1. Hydraulically Active: Normal state of operation
      2. Damped Bypass Mode: passively follows the working actuator

- **ELECTRICAL BACKUP HYDRAULIC ACTUATOR** **EBHA**
  - ONE (1) FOR EACH PRIMARY FLIGHT SURFACE



  - ONE (1) FOR EACH OUTBOARD SPOILER PANEL



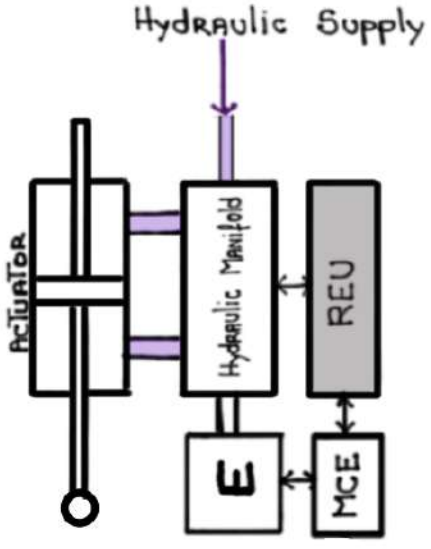
  - NORMALLY USES LEFT AND RIGHT HYDRAULIC SYSTEMS
  - NORMALLY COMMANDED BY AN REU → EBHA
  - IF NORMAL HYDRAULIC PRESSURE IS NOT AVAILABLE IT REVERTS TO ELECTRIC BACKUP (EB) MODE
  - THREE (3) MODES:
    1. HYDRAULICALLY ACTIVE: NORMAL STATE OF OPERATION
    2. DAMPED BYPASS MODE: PASSIVELY FOLLOWS THE WORKING ACTUATOR
    3. EB MODE

EB mode:

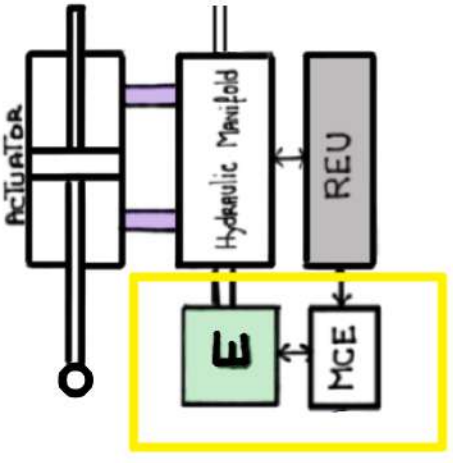
- Electric power to drive a pump at the actuator
- Pressurizes trapped hydraulic fluid
- Acts as a third Hydraulic System

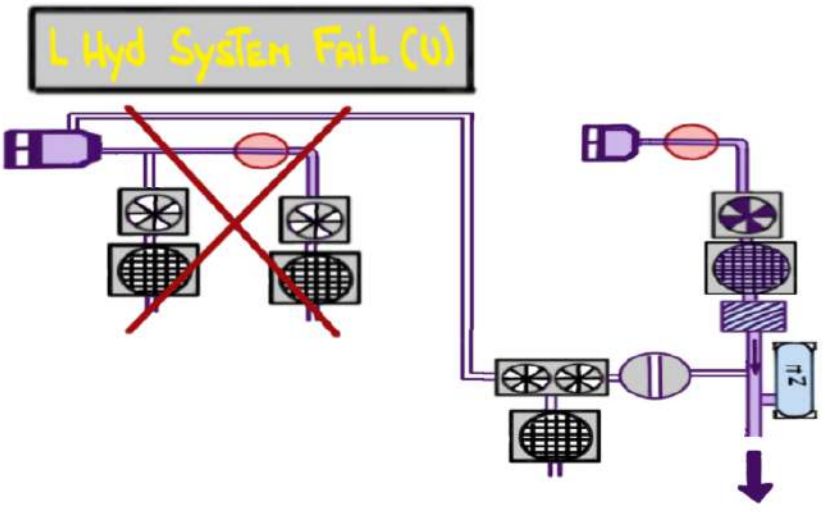
- A Motor Control Electronics (MCE) is used to control the EBHA motor-pump when the actuator is in the Electric Backup **E** state due to hydraulic or REU failures

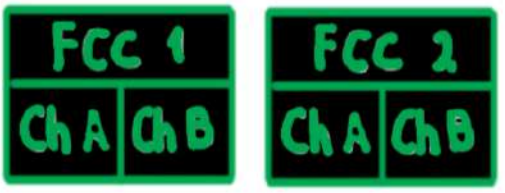
Hydraulically Active

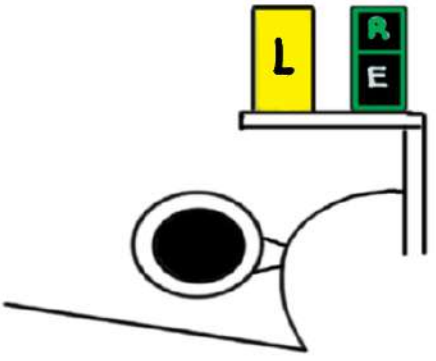


Electric Backup **E** Mode

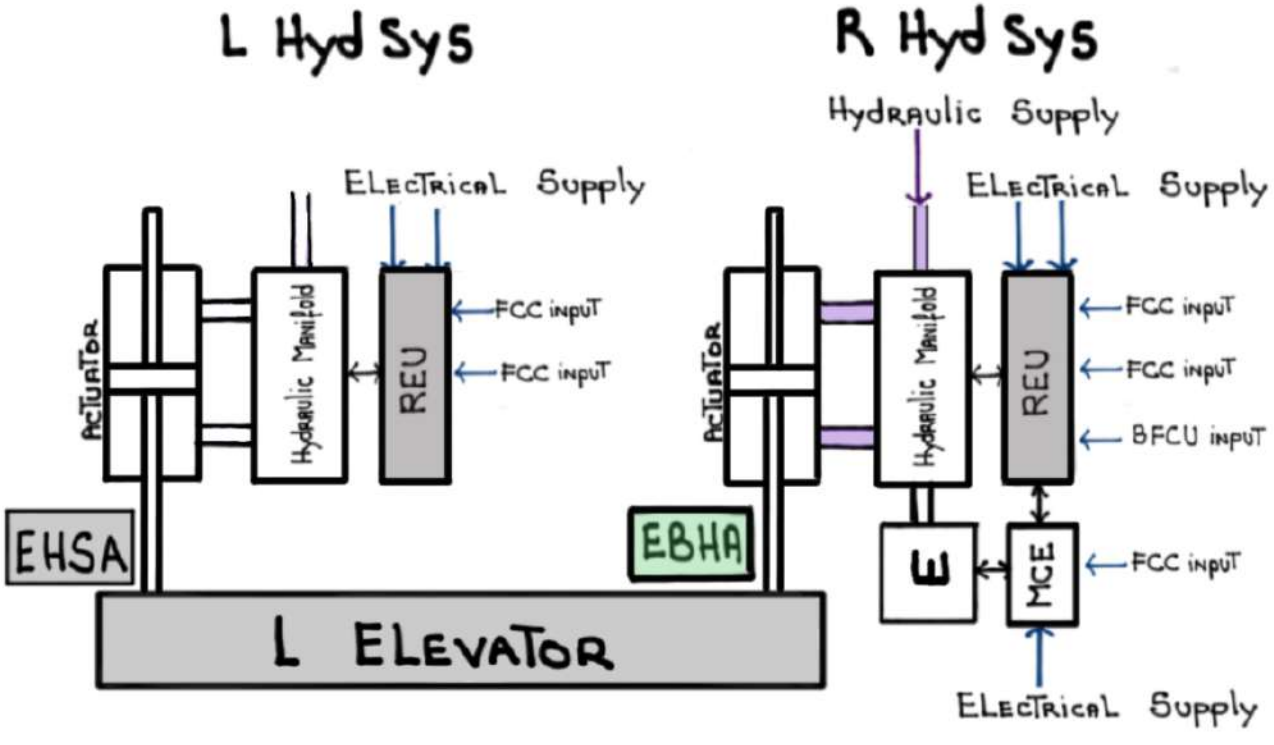


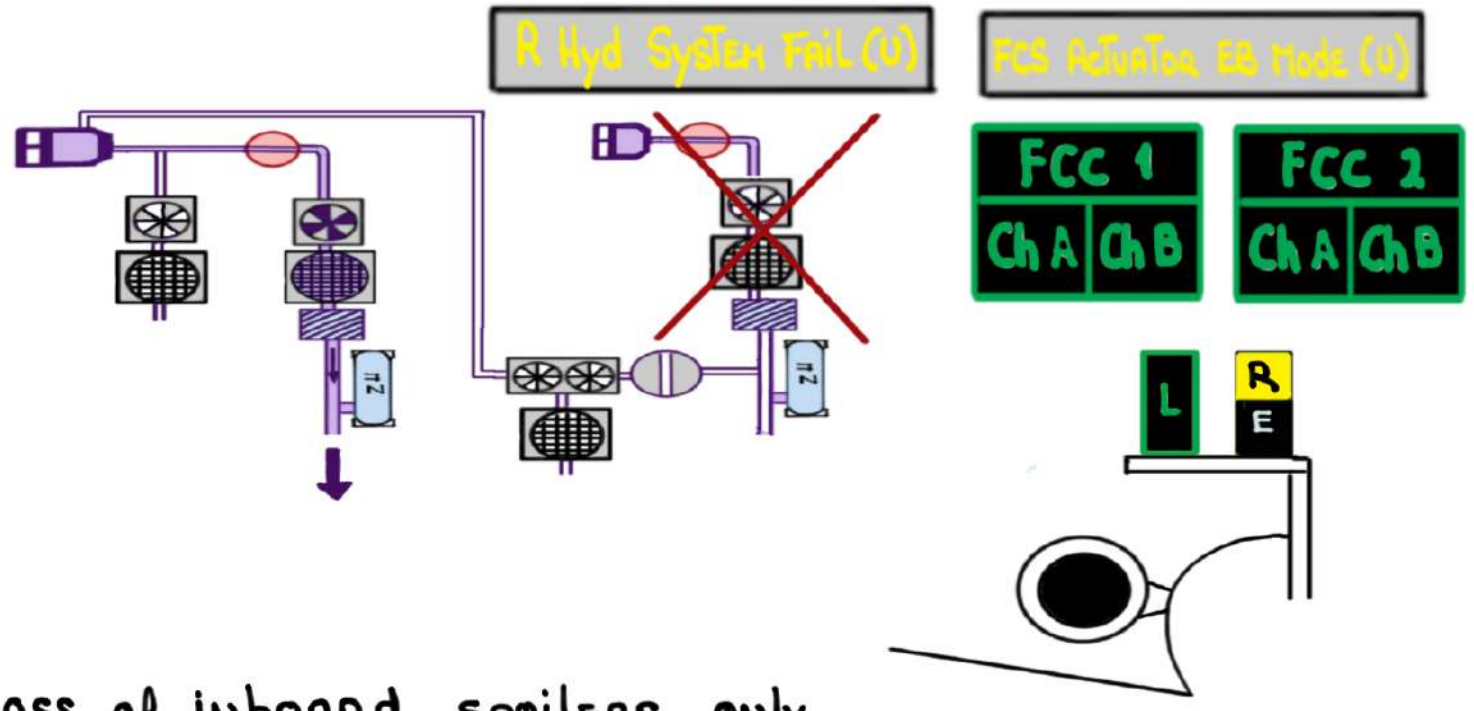




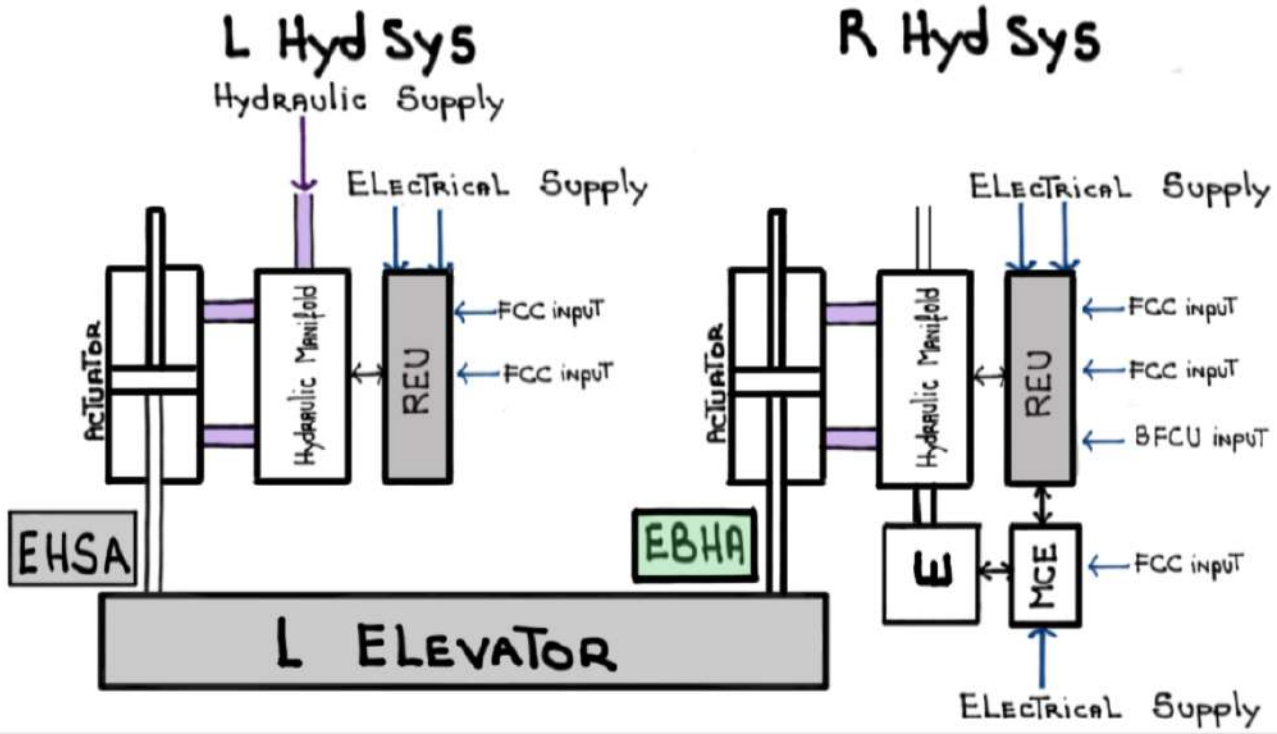


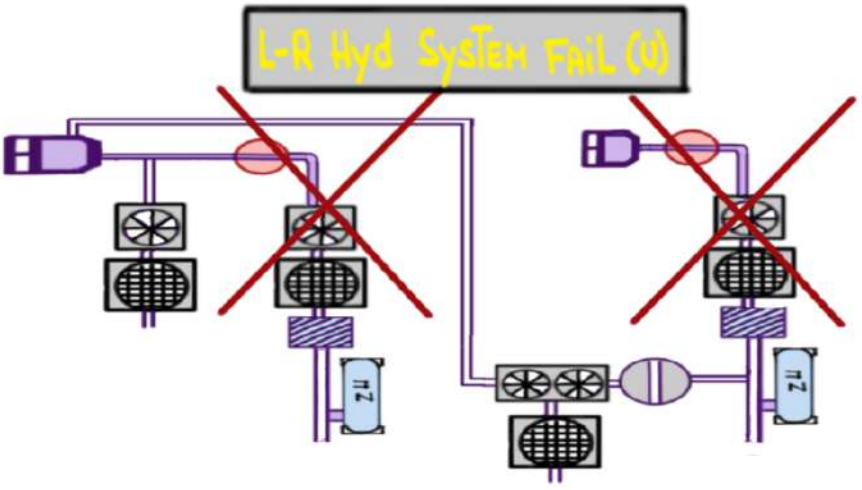
- Loss of midboard spoilers only
- All actuators powered by the left hydraulic system operate in damped bypass mode
- Maximum speed: 285 KCAS/M0.90

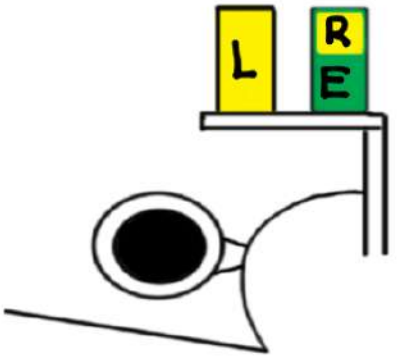




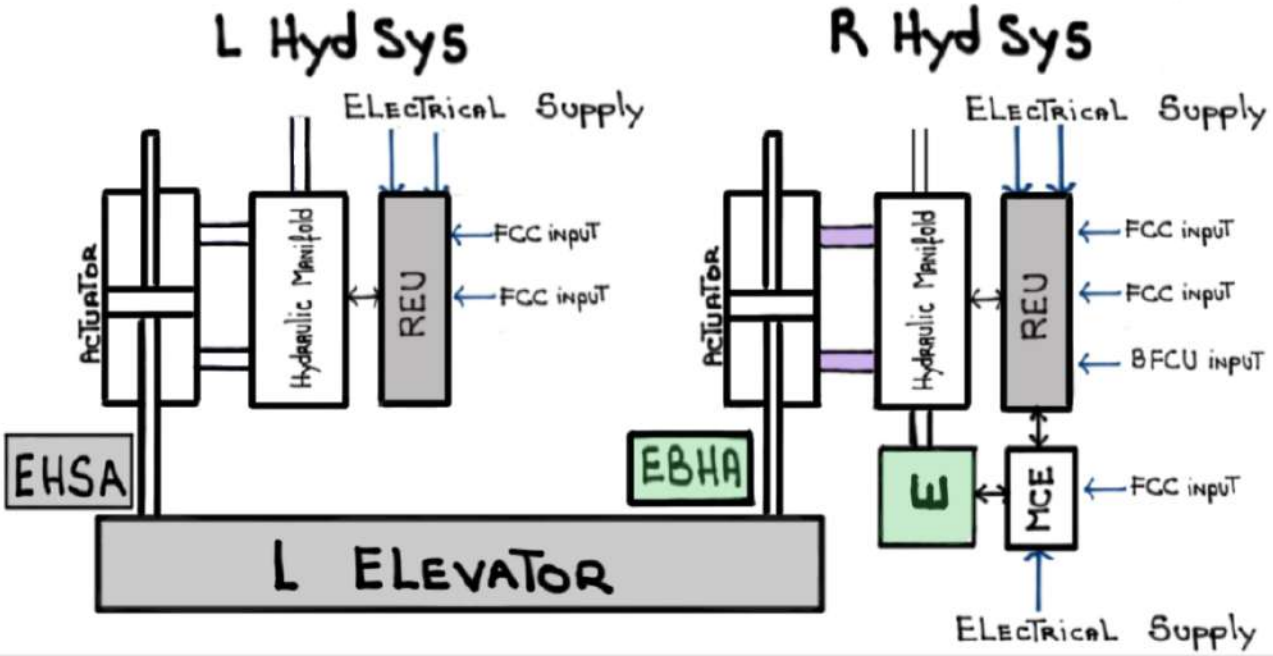
- Loss of <u>inboard</u> spoilers only
- Outboard spoiler actuators operating in EB E mode
- All other actuators powered by the Right Hydraulic System operate in damped bypass mode
- <u>Maximum</u> speed: 285 KCAS/M0.90





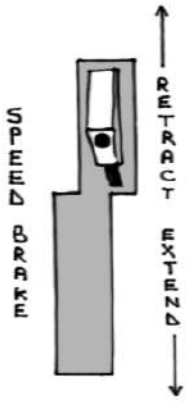


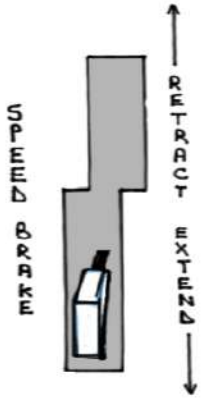
- Loss of midboard and inboard spoilers
- All EBHA actuators operate in EB E mode
- All other actuators operate in damped bypass mode
- Each flight control surfaces powered by a single actuator
- Maximum speed: 285 KCAS/M0.90



Spoilers

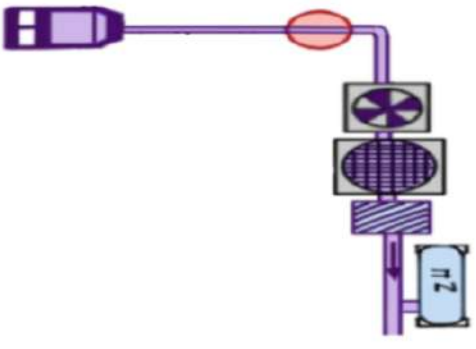
- **Electrically** - controlled via speed brake handle:

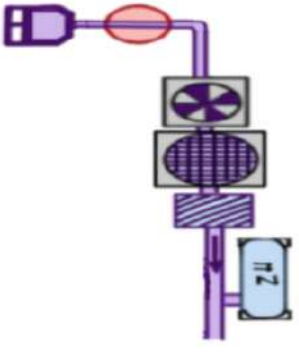




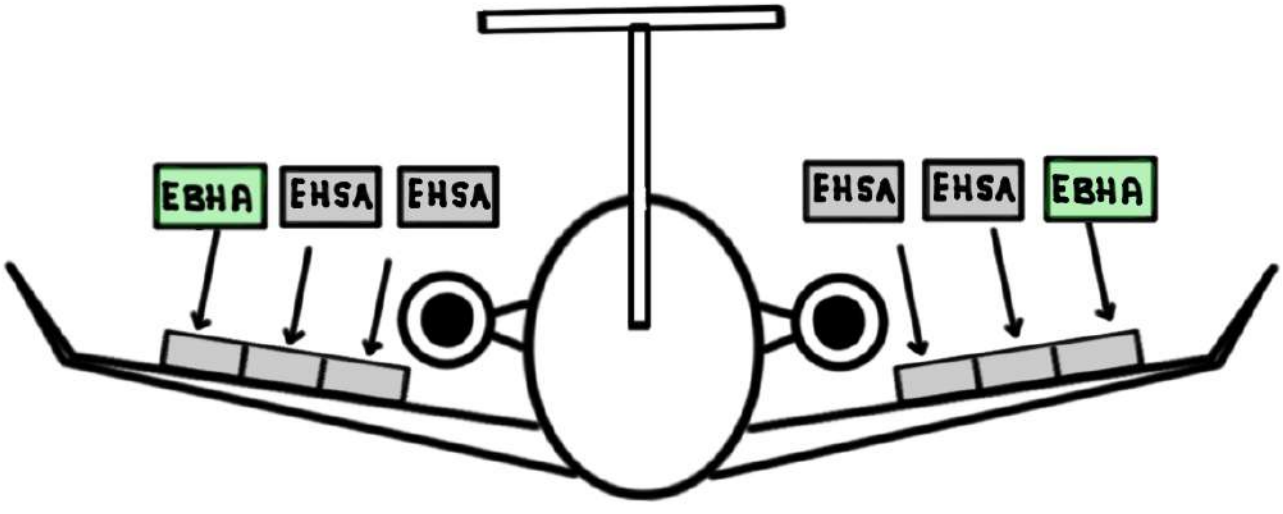
Speed Brake Extended

- **Hydraulically** - powered by:





Six (6) spoiler panels - One (1) actuator each



① Roll Augmentation – midboard and outboard panels

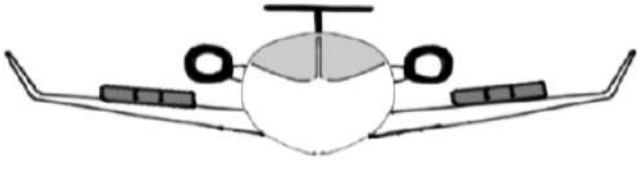
up To 55°

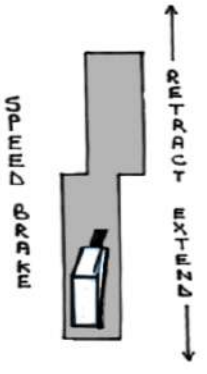
---

② Speed Brakes in-flight

up To 30°

Speed Brake Extended

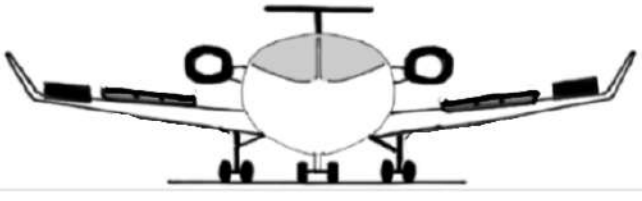




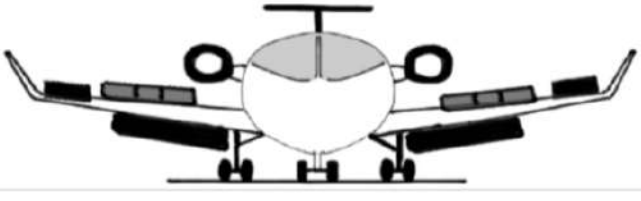
---

③ Ground Spoilers ON ground

Flaps < 10° : 30°

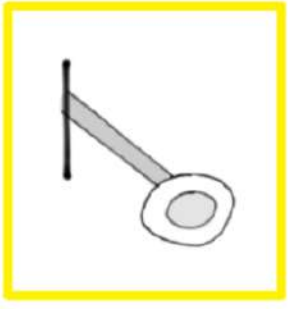


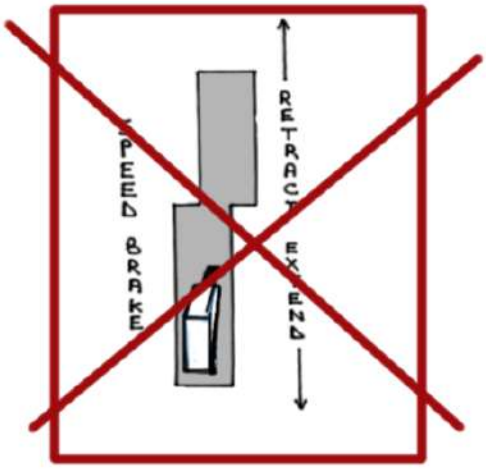
Flaps ≥ 10° : 55°



Do not extend spoilers inflight with gear down or flaps 39°

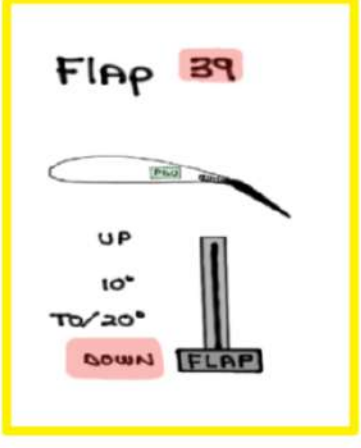
W | Landing Config | W





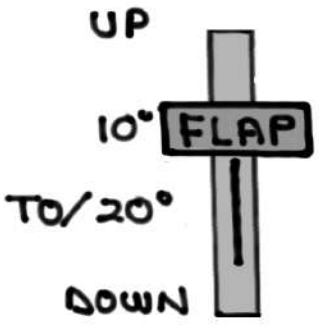
Prohibited

W | Landing Config | W

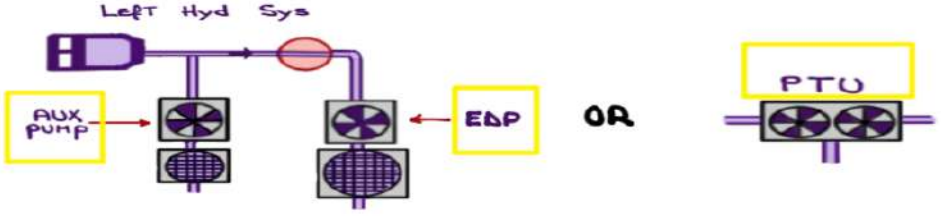


FLAPS

- **Electrically** - controlled by flap handle:



- **Hydraulically** - powered by:

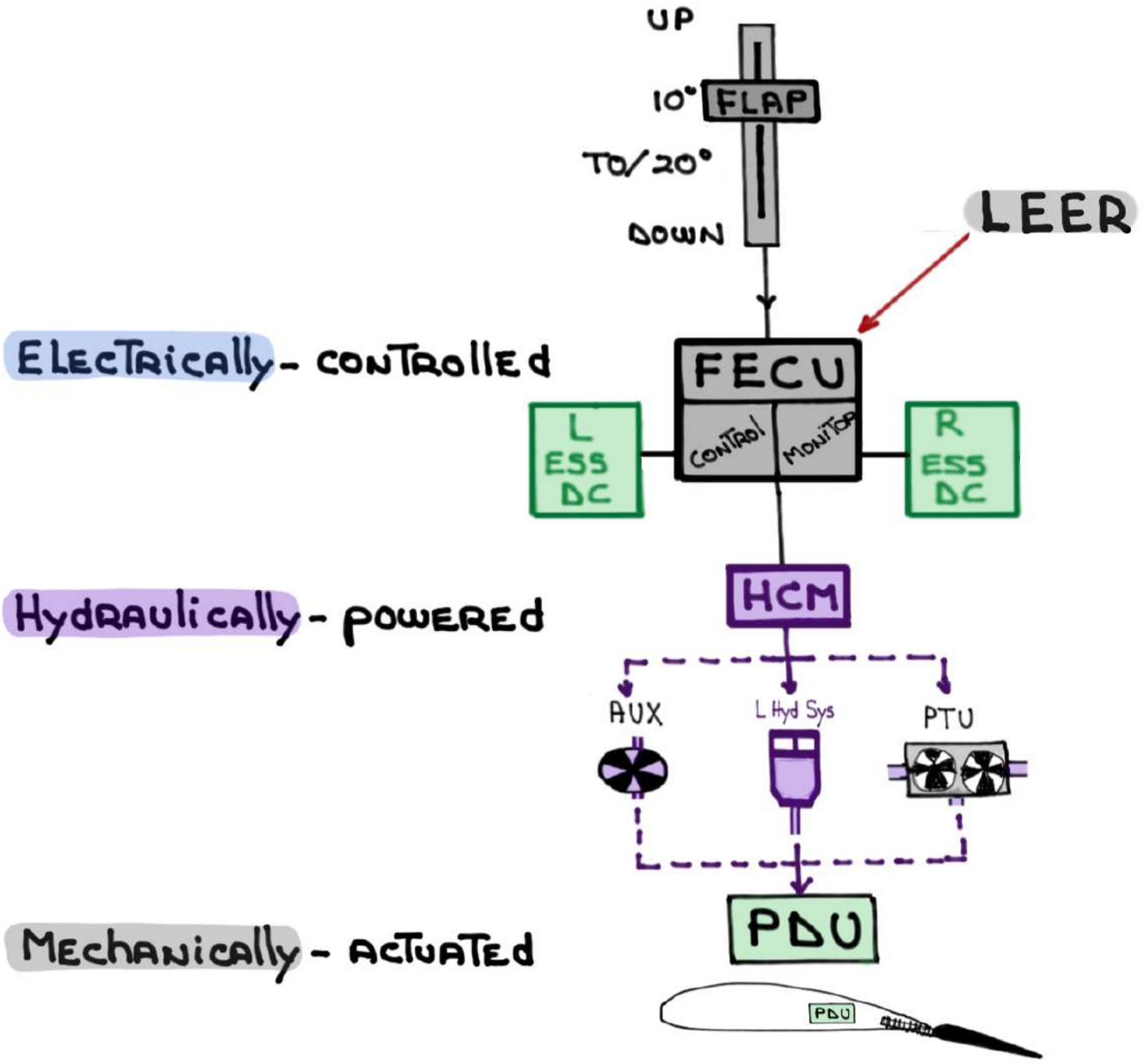


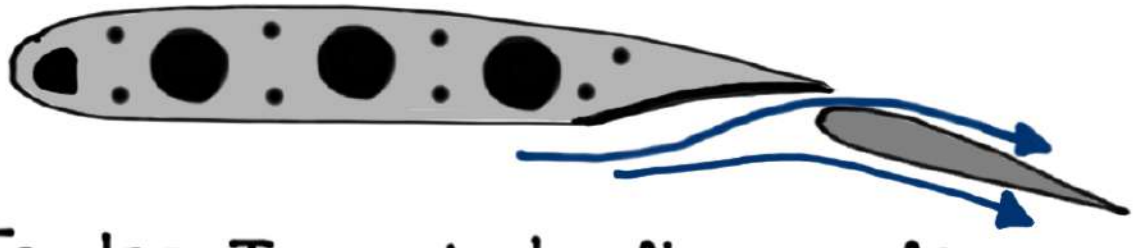
- **Mechanically** - actuated by:

  - Flap Electronic Control Unit **FECU**
    It commands flap movement by electrically controlling:

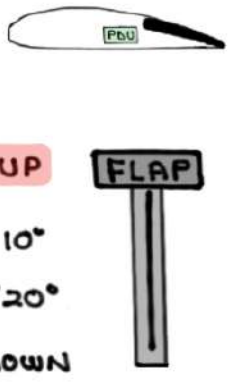
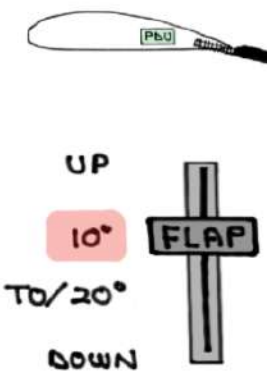
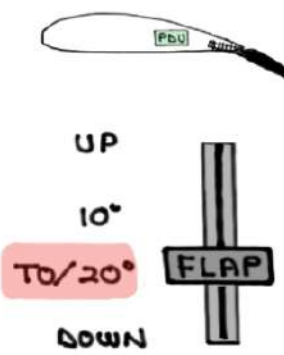
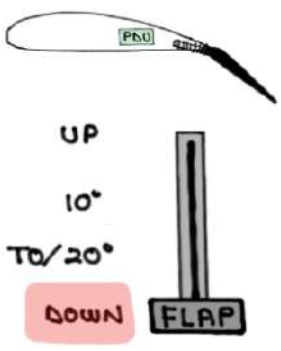
  - Hydraulic Control Module **HCM**
    The HCM controls hydraulic power to:

  - Power Drive Unit **PDU**
    The PDU drives the mechanical actuator

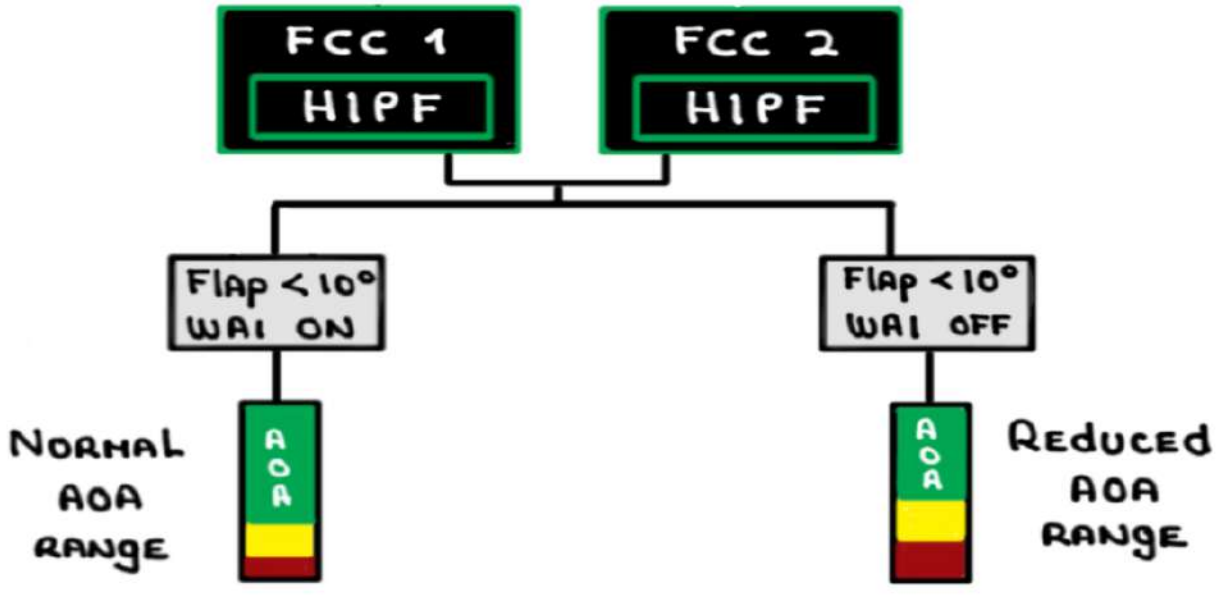




FOWLER-TYPE SINGLE FLAP SURFACE
(GREATEST AMOUNT OF LIFT FOR LEAST AMOUNT OF DRAG)

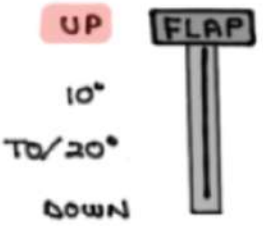
Flap 0	Flap 10	Flap 20	Flap 39
			
MAXIMUM EXTENSION/EXTENDED SPEED			
	VFE 250 KCAS	VFE 220 KCAS	VFE 180 KCAS
MAXIMUM G-LOADS			
-1 TO +2.5 g	0 TO +2 g	0 TO +2 g	0 TO +2 g 0 TO +1.5 g (> MLW)
MAXIMUM OPERATING ALTITUDE			
	≤ 25,000'	≤ 25,000'	≤ 20,000'

High Incidence Protection Function



- FCC stall protection software
- If landing with <10° of flaps (zero flaps) it assumes the wing is contaminated and artificially increases the Flaps 0° Vref
- It also limits the available AOA so that even with full aft control stick the minimum steady speed is not less than the reference stall speed (Vsr)

Flaps Failed (U)

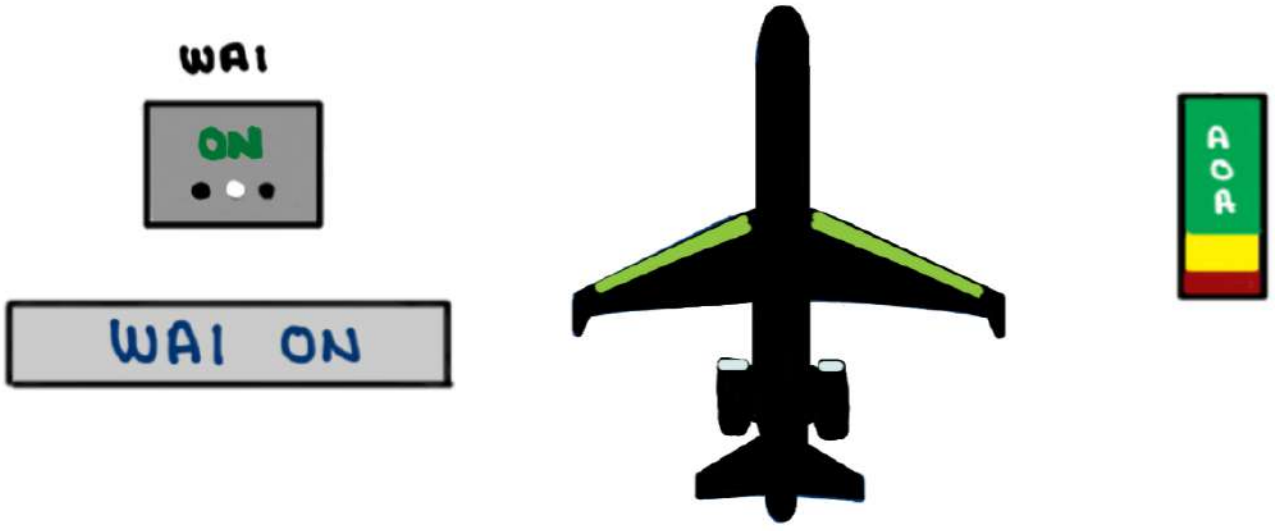


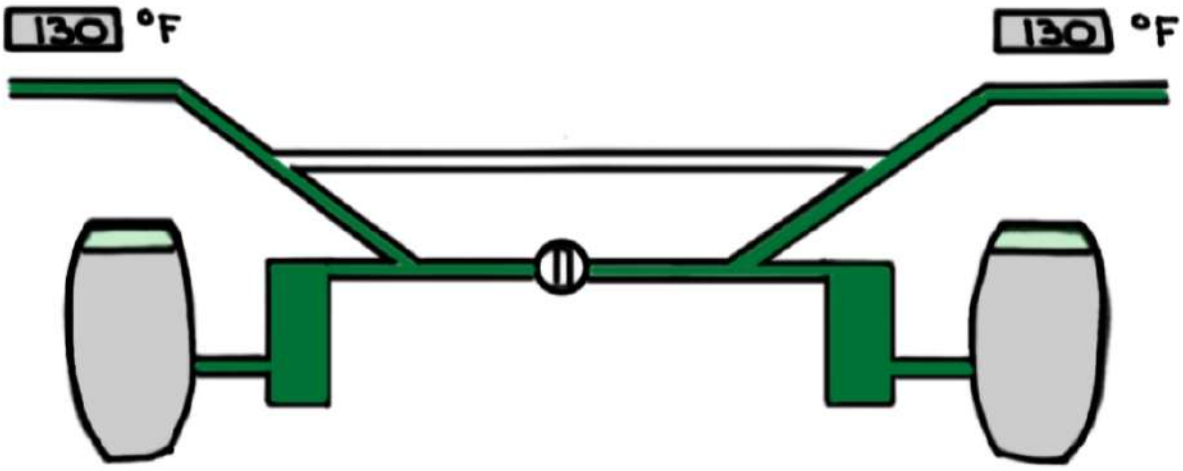
- Reduced usable AOA

  - PLI appears at a lower AOA
  - Stick Shaker activates at a lower AOA
  - Yellow and Red Speed Awareness Tapes appear at higher speeds

- Higher Approach and Vref speeds
- Slower engine response due to lower engine idle speed
- Longer landing distance required
- Hotter brake temperatures

Selecting Wing anti-ice ON <u>resets</u> the FCS Law logic for AOA protection back to normal





Wing Temperature <u>must be</u> > 100°F and aircraft altitude > 1,500' AGL for the control law logic to change

Horizontal Stabilizer Trim System (HSTS)

- Fully trimmable horizontal stabilizer control surface

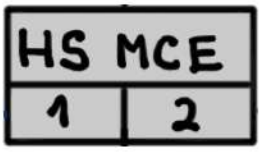
- Pitch trim is controlled by the trim switch on either Active Control Sidestick or Pitch Trim Switch on the pedestal

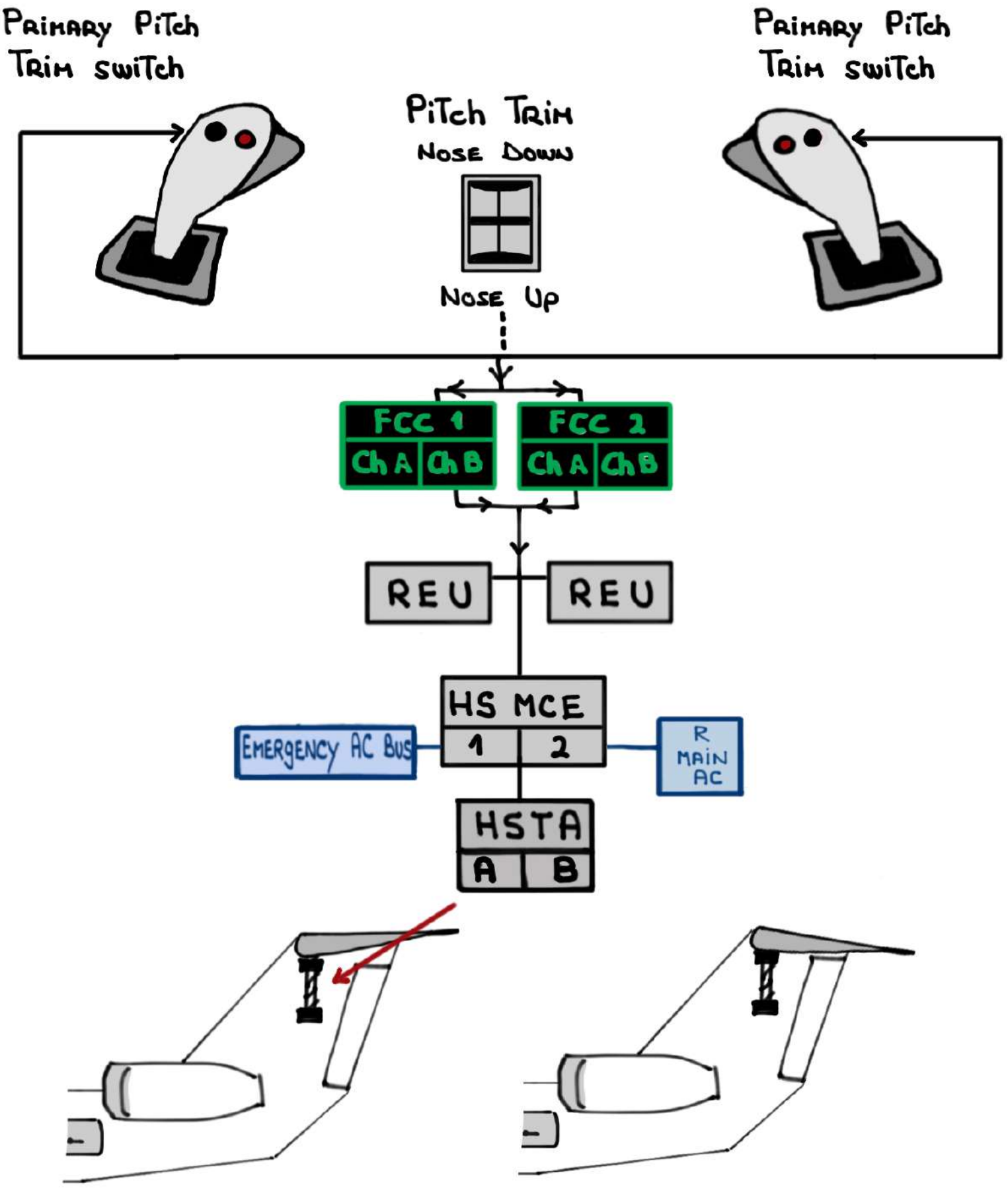
- Input from these switches is transmitted to:

- Output from the FCCs is transmitted to the REU

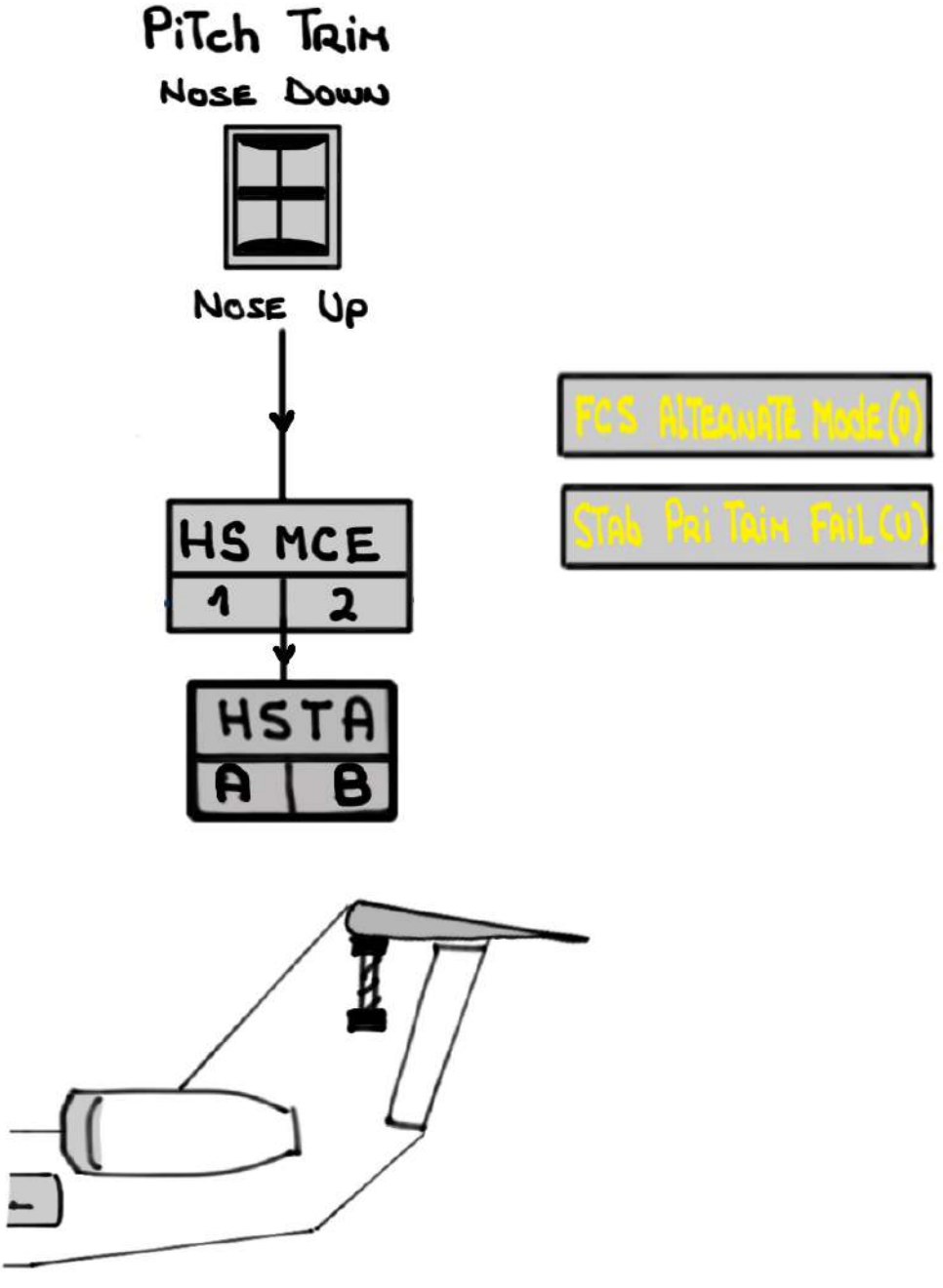
- Stabilizer surface is moved by the dual electric motor Horizontal Stabilizer Trim Actuator (HSTA)

- The HSTA (A | B) is electrically-controlled from the dual channel Horizontal Stabilizer MCE




Primary Pitch Trim switch
Primary Pitch Trim switch
Pitch Trim
Nose Down
Nose Up
FCC 1
Ch A
Ch B
FCC 2
Ch A
Ch B
REU
REU
HS MCE
1
2
Emergency AC Bus
R Main AC
HSTA
A
B

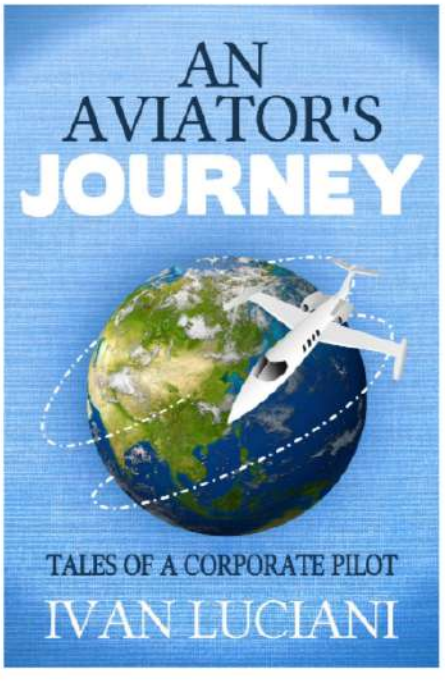
In the event of loss of communication from the FCCs the sidestick pitch trim switches won't be available.
The pedestal switch bypasses the FCCs and signals the HS MCE. The stab moves at a constant rate

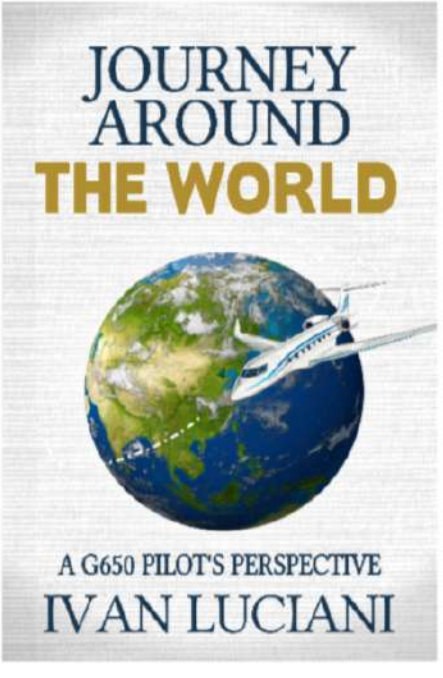


REMINDER: these system notes are intended for study purposes only. Always refer to official Gulfstream manuals and other approved references when operating your aircraft.

NOTE: these system notes are updated from time to time and what is posted on Code450.com will always be the most recent version.

Questions, comments or errors...please do send me an email: ivan.luciani@gmail.com





Thank you!