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SubcommitteD/F35 AIS Krumenacker
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ACTIVE STICK & THROTTLE FOR F-35

Joseph Krumenacker
NAVAIR Flight Controls / JSF Vehicle Systems
16 October 2008

Intro

Joe Krumenacker holds a BS in Aerospace & Mechanical Engineering from the University of Notre Dame, and previously worked for Grumman in aerodynamics, flight controls and flight test on the X-29 and F-14 programs. He joined the NAVAIR Flight Controls Branch in 1996 and has worked on the Joint Strike Fighter since 1999. He currently leads the JSF Program Office's Vehicle Control Integration team.

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JSF Active Inceptor System (AIS)

Presentation Overview

A. Why & What of Active Inceptors:

- JSF Inceptor Overview & Architecture
- Reconfiguration for AIS Degraded Modes
- AIS Specification Issues

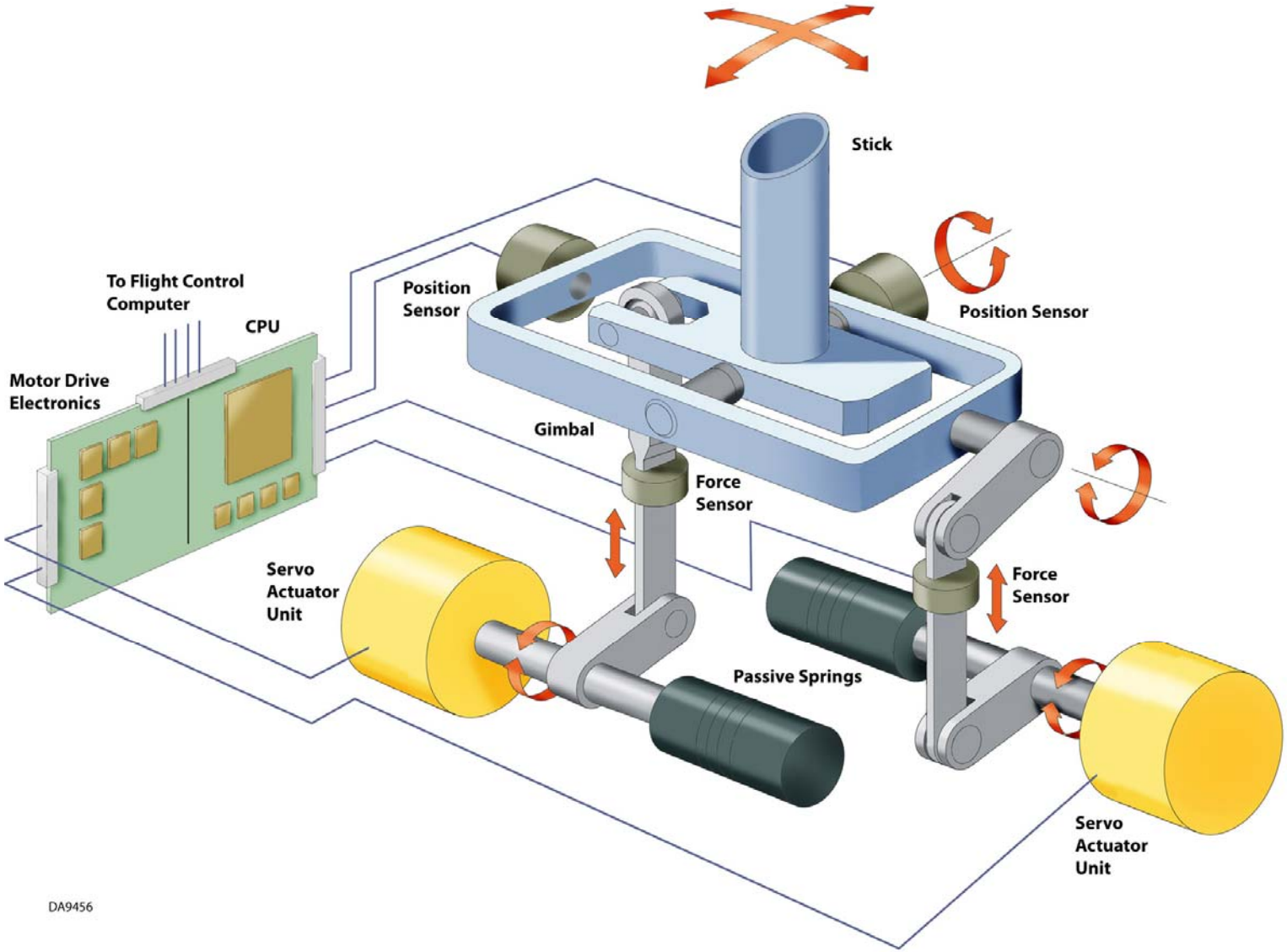
B. How have Active Inceptors been put to use:

- Current Uses of Active Capability
- Jetborne Advanced Modes Using Active Capability
- Lessons Learned

C. Conclusions

Active Inceptor Overview

BAE SYSTEMS



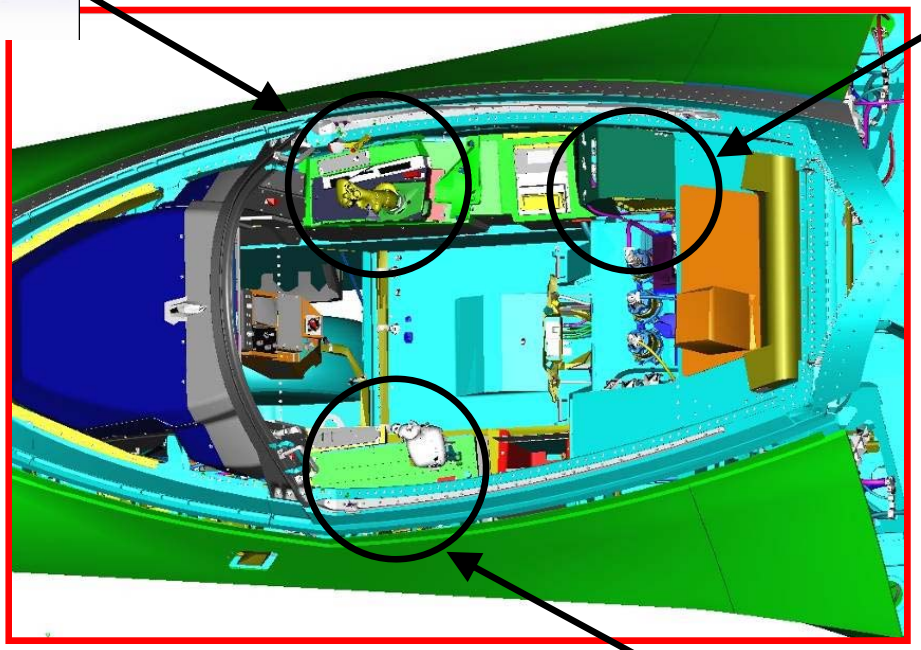
Why Were Active Inceptors Chosen?

- **Design Flexibility for STOVL Advanced Control Law**
  - JSF specification prohibits the use of a third inceptor and requires a pilot interface that minimizes both pilot workload and cognitive error potential.
- **Throttle Back-drive Capability**
  - PA Approach Power Compensation (Auto-Throttle)
  - UA Speed Hold Modes
  - STOVL Performance Protection & Auto-Deceleration Modes
- **Commonality Between CTOL, STOVL and CV Variants**
- **Active Stick & Throttle Had Already Been Proven on X-35 Demonstrator**
  - X-35 active throttle had a separate nozzle control lever

AIS Installation Overview

SideStick (ASSCA)

FWD

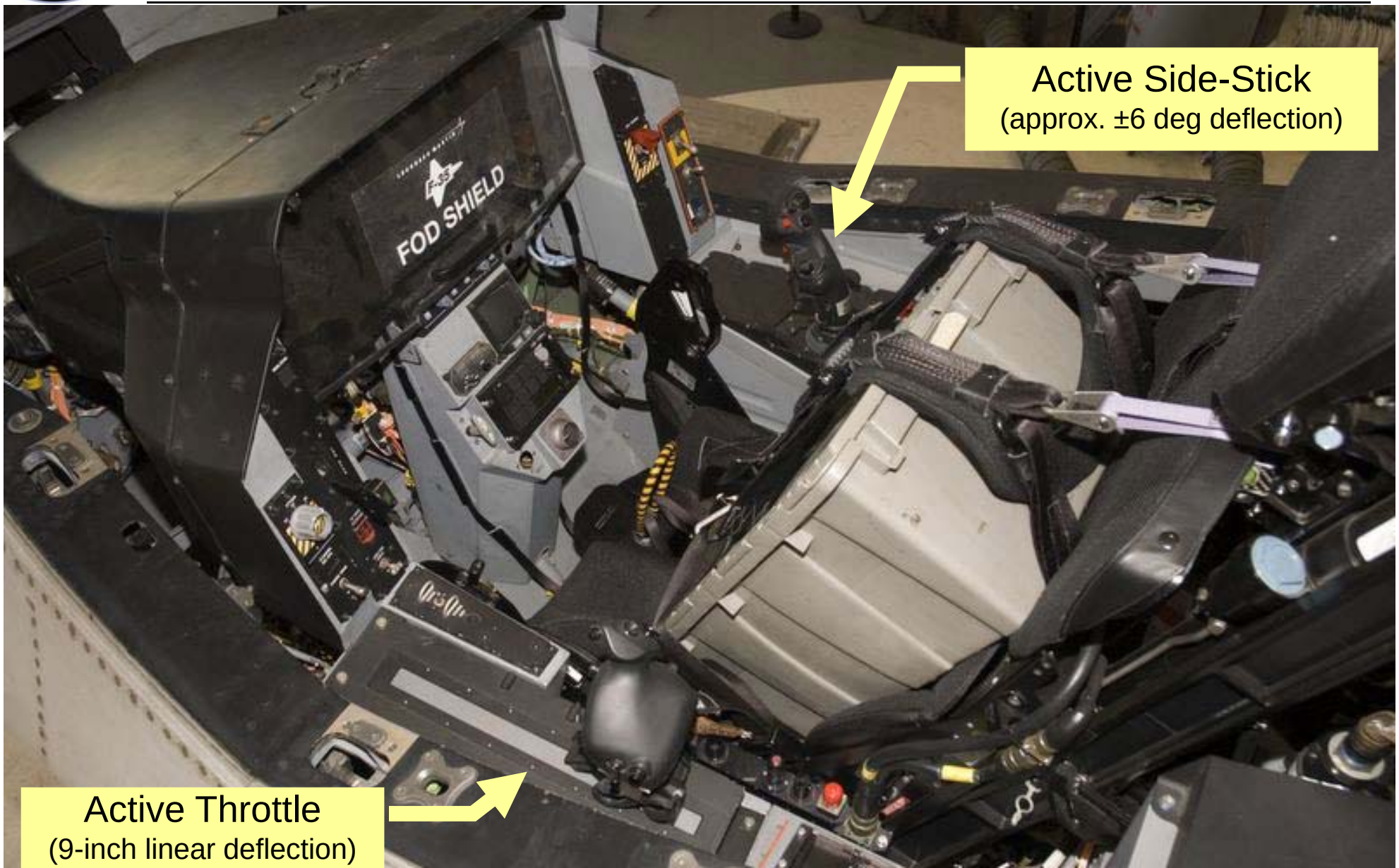


Inceptor Control Unit (ICU)

- All JSF variants (CTOL, STOVL & CV) use identical AIS hardware & software.
- AIS is provided as a complete system by BAE, Rochester UK
- Stick & Throttle grips not procured as part of AIS.

Throttle (ATQA)

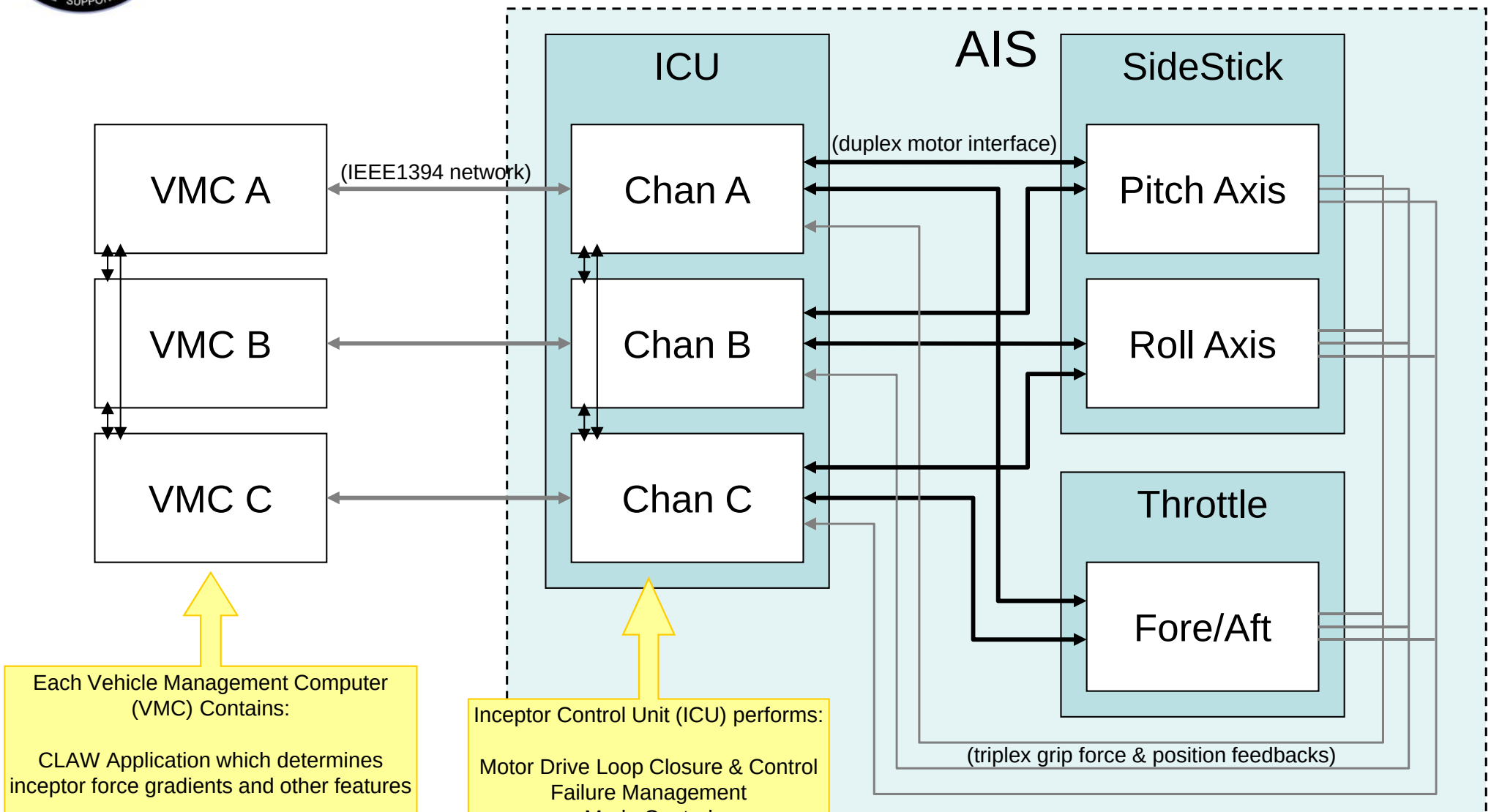
F-35 AA-1 Cockpit



Inceptor Characteristics

- **Three Axes of Control: Stick Pitch, Stick Roll, Throttle**
- **Each Axis contains duplex 28V electric motor drives connected to grip interface by mechanical linkages**
- **Each Axis contains triplex force and position sensors**
- **Stick Axes contain mechanical springs for backup mode**
- **Grips (and various HOTAS switches) are supplied by separate vendor, but are qualified for flight together with the stick & throttle.**

VMC & Inceptor Architecture



AIS Modes & Fault Accommodation

- **Each Inceptor has three primary control modes:**
  - **Active**: sensed grip force is used to actively position the inceptor according to the programmed force vs. position characteristics
    - Flight Control Laws use inceptor position as pilot command
  - **Passive**: motor drives disengaged, stick springs provide fixed linear force gradient, throttle has fixed friction & no detents
    - Used upon unrecoverable error with motor drives
    - Flight Control Laws use stick forces and throttle position as pilot command
    - Both stick axes will maintain like mode (if one axis downgrades passive mode, other axis will be place passive mode)
  - **Jammed**: inceptor position is fixed
    - automatically detected by software
    - Flight Control Laws use inceptor force as pilot command
    - jammed throttle requires some Control Law reconfiguration

Active Inceptor Requirements & Specification Issues

Programmable Inceptor Active Mode Characteristics:

- force gradients/ramps
- forward & aft end stops
- variable damping
- force gates & soft-stops (e.g AB)
- pilot-adjustable friction force (throttle)
- force detents (STOVL)
- position back-drive (auto-throttle modes)

Inceptor Specification Issues:

- force capability (static and dynamic)
- force accuracy/variability
- velocity capability
- motor drive redundancy
- electronics redundancy
- force sensor null drift & sensor noise characteristics
- passive mode centering (stick)
- passive mode breakout and force gradients (stick)

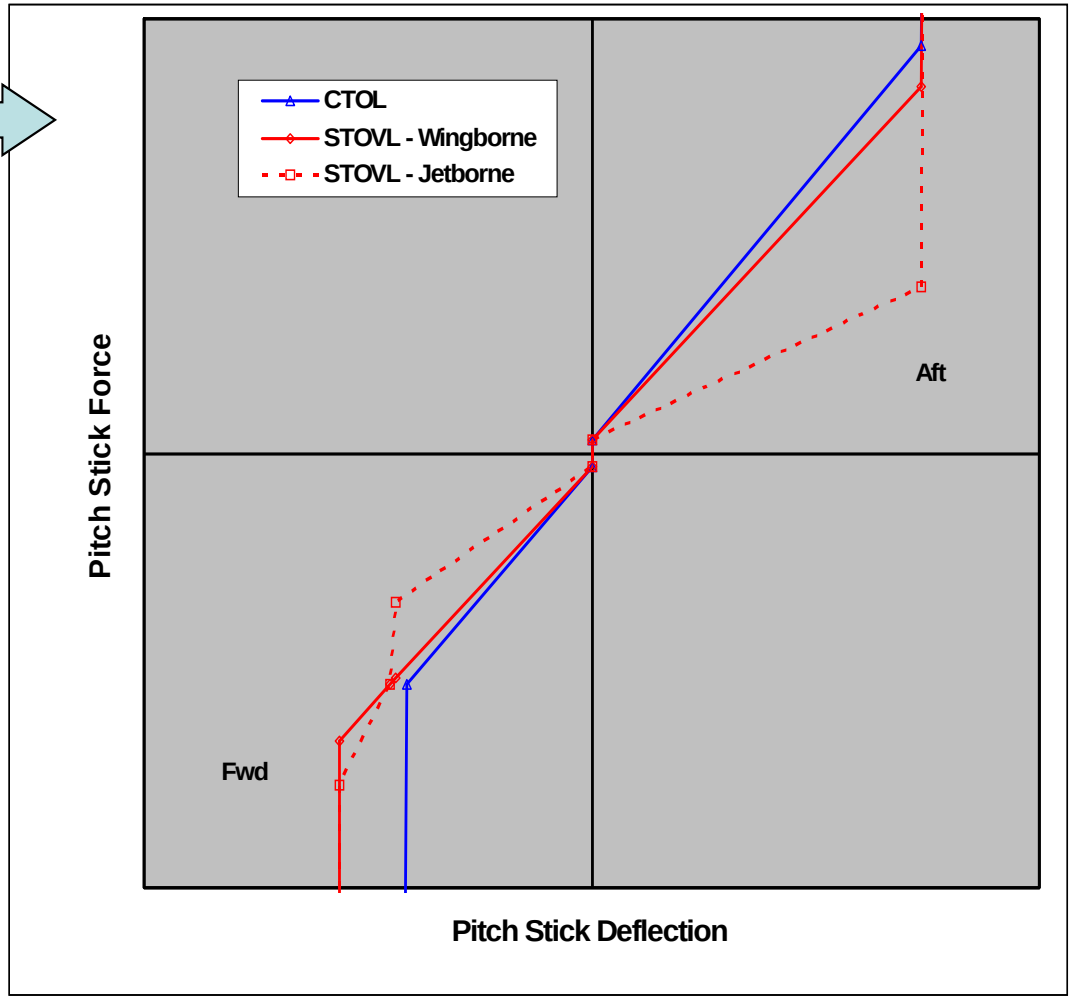
Blue shaded items are less configuration-dependent than others and could benefit from industry-wide specifications or guidance.

How Is Active Capability Currently Used?

- **Throttle:**
  - Variable aft & forward end-stops (e.g. STOVL mode is different from CTOL mode)
  - AB gate (when STOVL system is not deployed)
  - Launch gate (CV only)
  - STOVL center detent (zero commanded acceleration)
  - STOVL on-ground power braking force gradient
  - Back-drive
    - Auto-Throttle Approach (all variants)
    - STOVL Decel-to-Hover

How Is Active Capability Currently Used?

- **Stick:**
  - Tailored STOVL pitch force characteristics
    - wingborne vs. jetborne variations
    - forward soft-stop(s) for vertical landing sink speed
  - Pitch force feedback at higher AOA
  - Roll force tailoring: left vs. right
  - Roll force tailoring: CTOL vs. STOVL
  - Increased force breakout for CV launch (pitch & roll)



Background: F-35B Jetborne Control Strategy

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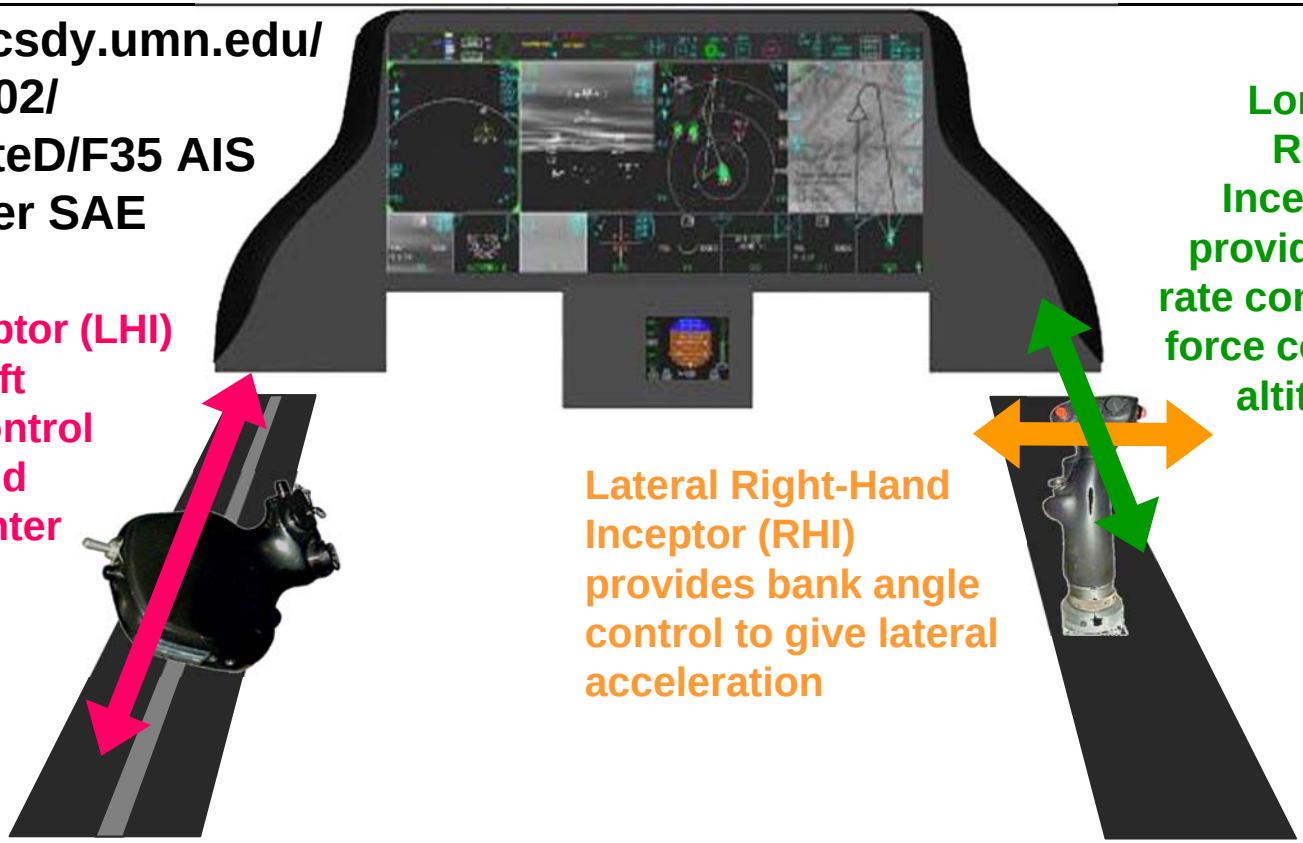


Left-Hand Inceptor (LHI) provides fore/aft acceleration control (with speed hold function on center detent)

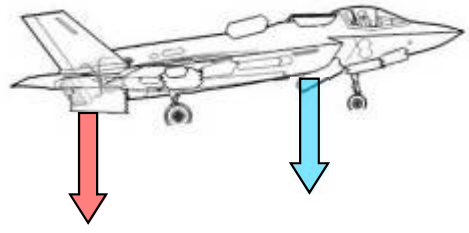
Lateral Right-Hand Inceptor (RHI) provides bank angle control to give lateral acceleration

Longitudinal Right-Hand Inceptor (RHI) provides height rate control (zero force commands altitude hold)

Full matrix of STOVL tasks can be flown by using only the two primary inceptors in a consistent manner throughout the flight envelope.

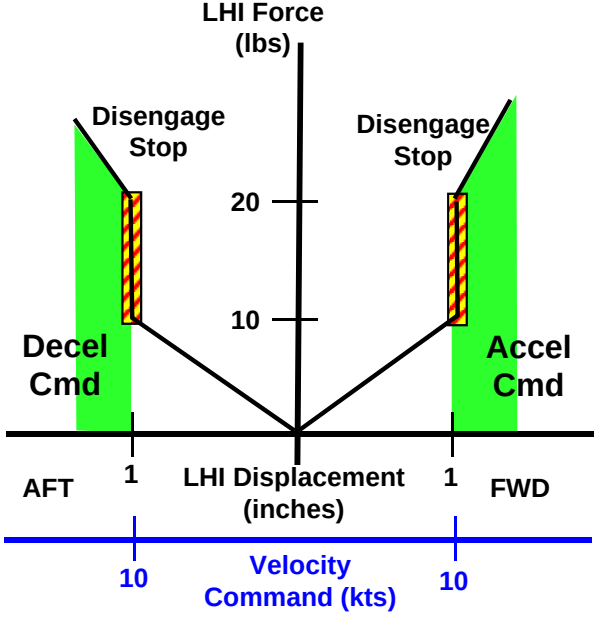
- Nozzle / thrust vector control not required in flight
- Cognitive error potential minimized by consistent inceptor functionality
- HOTAS functions can be added to provide additional hover control options

Further Advancements Using Active Inceptors: TRC Mode

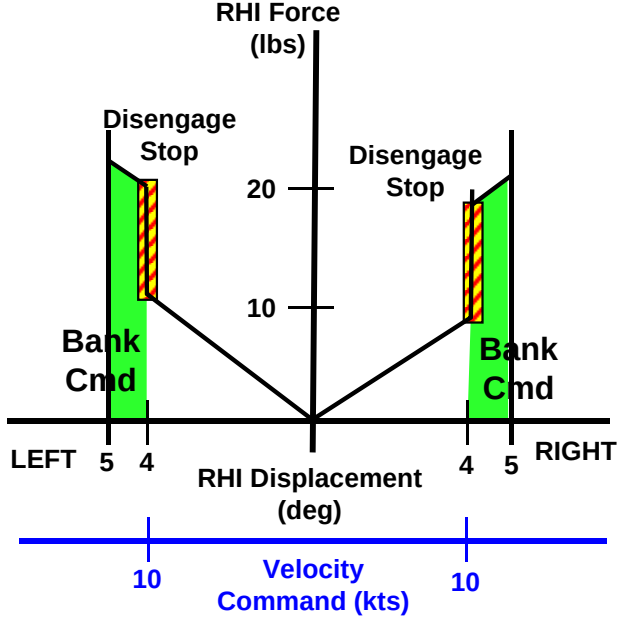


TRC = Translational Rate Command

LHI (Throttle) Characteristics



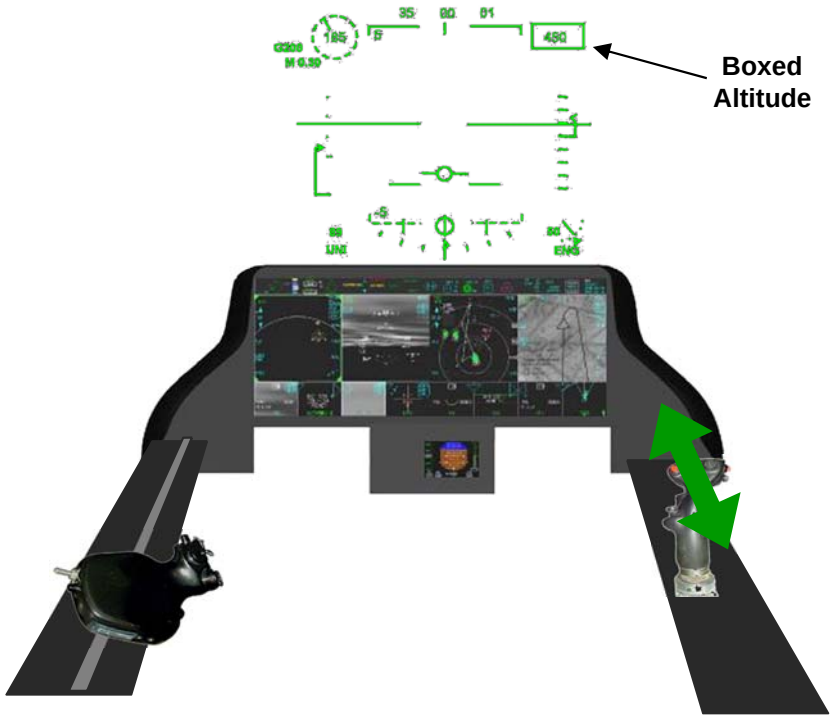
Lateral RHI (Stick) Characteristics



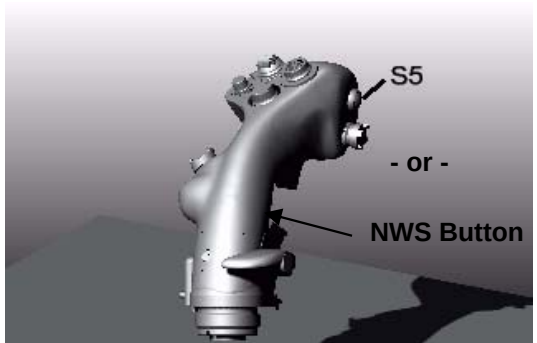
- Engage / Disengage via HOTAS Switch
- Velocity Trim via Speedbrake switch
- Disengage via Force Breakout
- Disengage via Paddle Switch

Potential Option for Longitudinal Stick: Height "Gripper"

- Proposed Change to Jetborne Height Axis: Pitch Stick would command altitude acceleration instead of the baseline altitude rate.
  - releasing the stick would no longer command zero sink rate (altitude-hold), so some other means of low-workload height hold was required
  - solution was a pilot-engageable "gripper" mode, in which an altitude-hold augmentation could be quickly engaged and disengaged
  - with gripper engaged, longitudinal stick breakout force is significantly increased to prevent inadvertent disengagement
  - Altitude Rosette is Boxed on Engagement
  - Manual Disengage to start descent rate
- Pros
  - Hover stick force is "significantly higher" and provides pilot direct tactile feedback and confirmation that the flight control system is in control of height axes
  - Push through or paddle off to begin vertical landing
- Cons
  - Remembering to select height hold
  - More buttons required



Engaged with S-5 switch
Altitude Gripper Breakout: +/- 20 lbs



AIS Lessons Learned

- **Level 1 flying qualities for precise STOVL tasks are possible using a small, limited-displacement stick, due to the ability to set jetborne-specific stick characteristics without compromising wingborne flying qualities.**
- **Passive and jammed modes can be accommodated with only minor flying qualities degradations**
  - throttle control in jammed mode perhaps the greatest challenge
- **Inceptor back-drive capability can be used to provide critical insight and training to the pilot in a very intuitive manner**
  - power approach auto-throttle as a training aid
  - STOVL auto-decel and performance deficit protection
  - (potential) high AOA cueing

Conclusions

- **JSF is committed to use of active inceptor system (AIS) for all three aircraft variants – production-representative AIS has been flying on AA-1 aircraft since December 2006.**

- **AIS has provided a valuable level of design flexibility both for the existing vehicle control laws and for the resolution of any yet unknown flying qualities shortcomings.**

- **AIS team has been challenged by environmental requirements for force sensors, and has worked hard to ensure force feel characteristics and redundancy management meet vehicle needs.**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STOVL