ENSURING SUCCESS OF ADAPTIVE CONTROL RESEARCH THROUGH PROJECT LIFECYCLE RISK MITIGATION

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Purpose of Presentation

Varied risk mitigations throughout a project lifecycle can support aggressive yet successful flight test

Outline

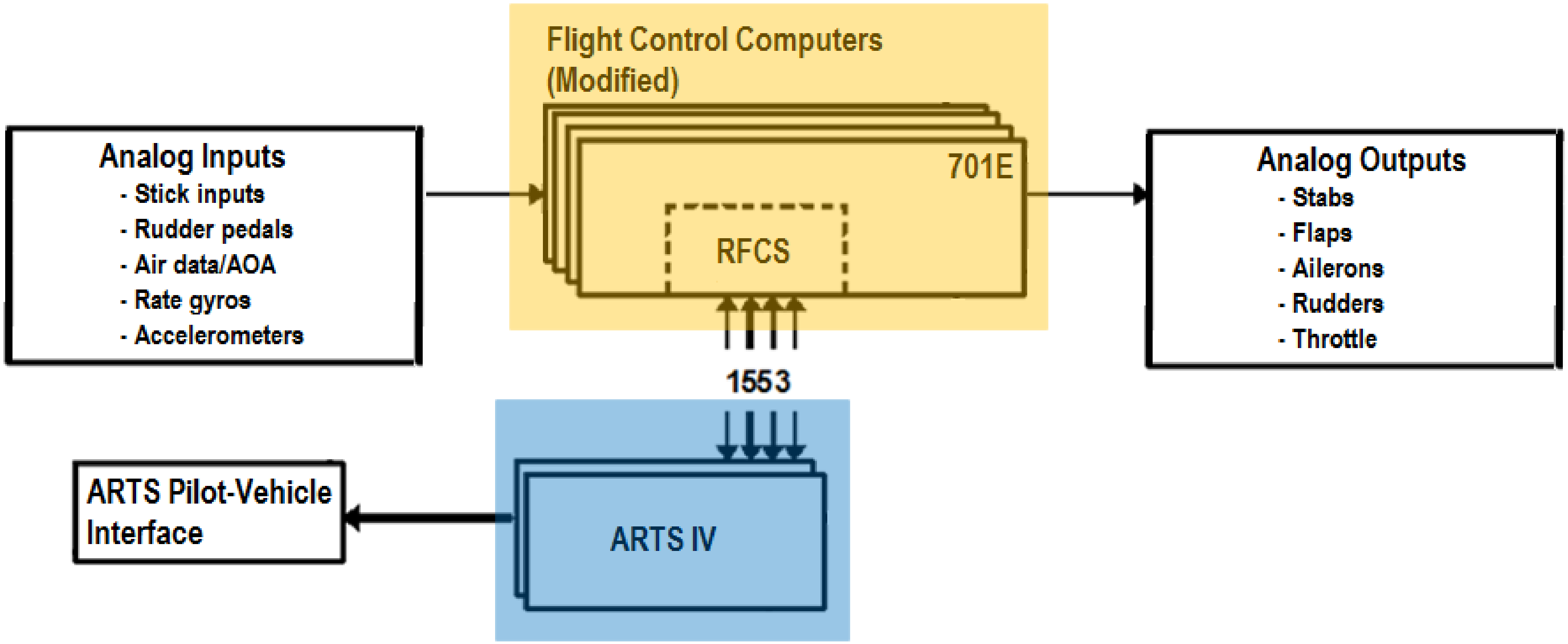
- Project background
- Research interface architecture
- Risk mitigations
- General flight test approach
- Model Reference Adaptive Controller (MRAC)
- Lessons Learned
- Conclusion

Background

Can adaptive control systems help in adverse conditions?

- Full-Scale Advanced Systems Testbed (FAST)
  - Relate adaptive control complexity to pilot performance

Research Interface Architecture
FAST modifications



701E = baseline flight control computers (FCCs)
RFCS = Research Flight Control System
ARTS = Aircraft Research Test System

*simplified figure

Research Interface Architecture
experimental modes

- <u>RFCS Primary:</u>
  - RFCS replicated F-18 production control laws sent to the 701E
- <u>RFCS/ARTS:</u>
  - RFCS & ARTS IV commands sent to the 701E
- <u>ARTS Primary:</u>
  - ARTS IV commands replace RFCS commands to the 701E

Experiment Selection

- Dial-A-Gain (DAG)

Experimental Mode	DAG
RFCS Primary	0
RFCS/ARTS Mode	1-13
ARTS Primary	14 – 26

- Choose-A-Test (CAT)

Experiment Category	CAT
No Failures	0
Simulated Failures: (control surfaces/throttles)	1-4
	5-8
	9
On-board Excitation System (OBES) RFCS	10-13
Frequency sweeps/doublets • collective • differential	14-15
On-board Excitation System (OBES) ARTS Doublets (low-high)	16-18

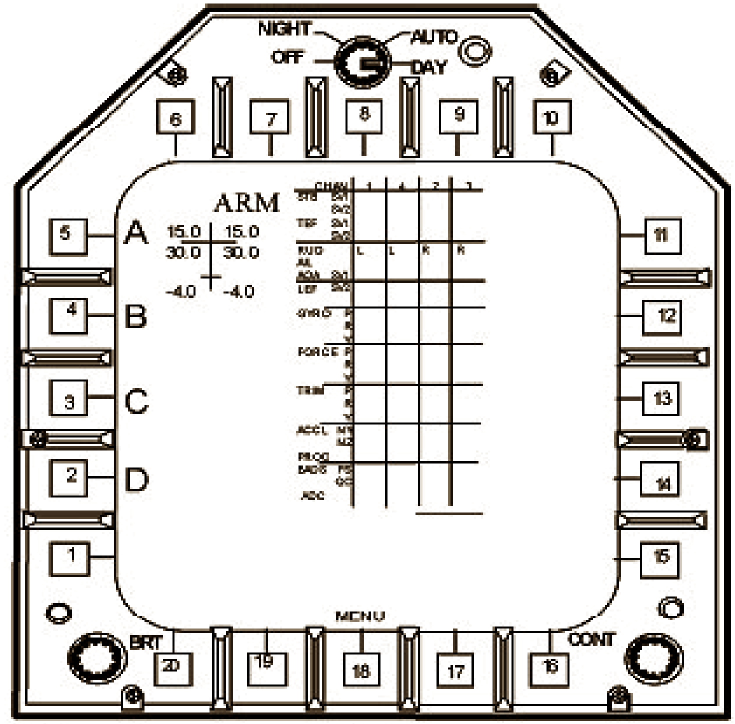
Risk Mitigation

- Primary techniques used:
  - design
  - detailed documentation
  - simulation

Risk Mitigation – Design
3-state control transfer

- Disengaged:
  - 701E in control; no RFCS
- Arm:
  - RFCS replication laws generate
- Engaged:
  - control handed to RFCS

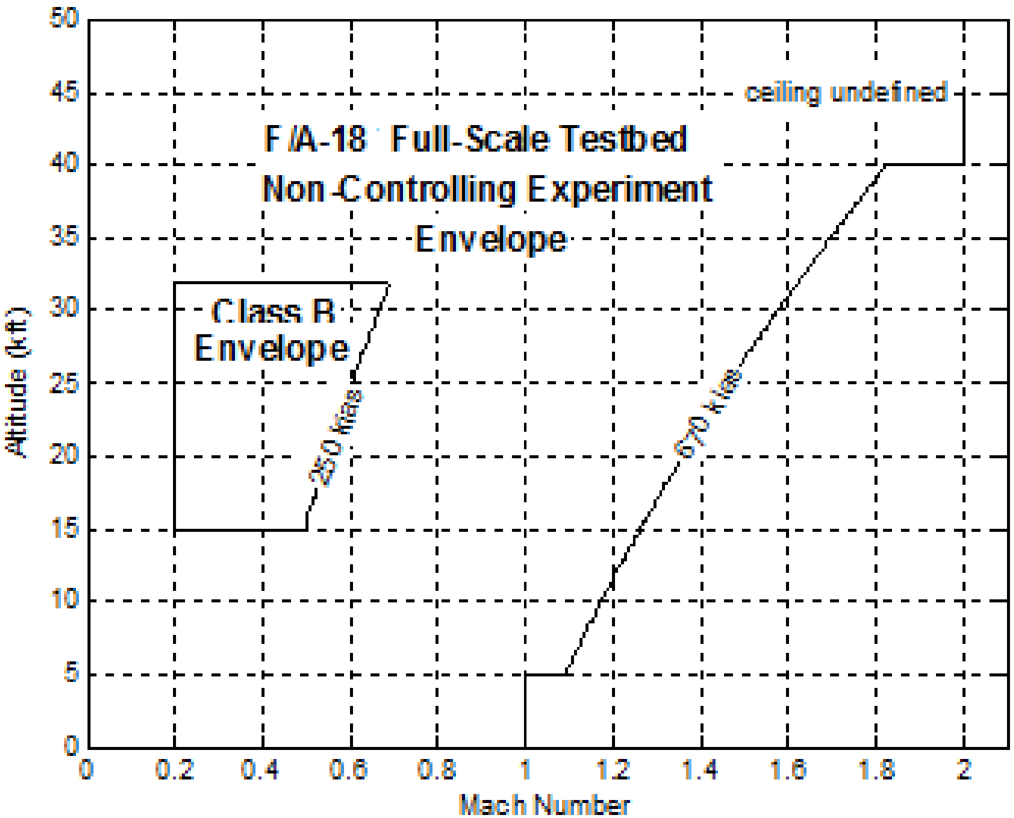
Reduce single-point failures



Digital Display Indicator (DDI)

Risk Mitigation – Design
RFCS

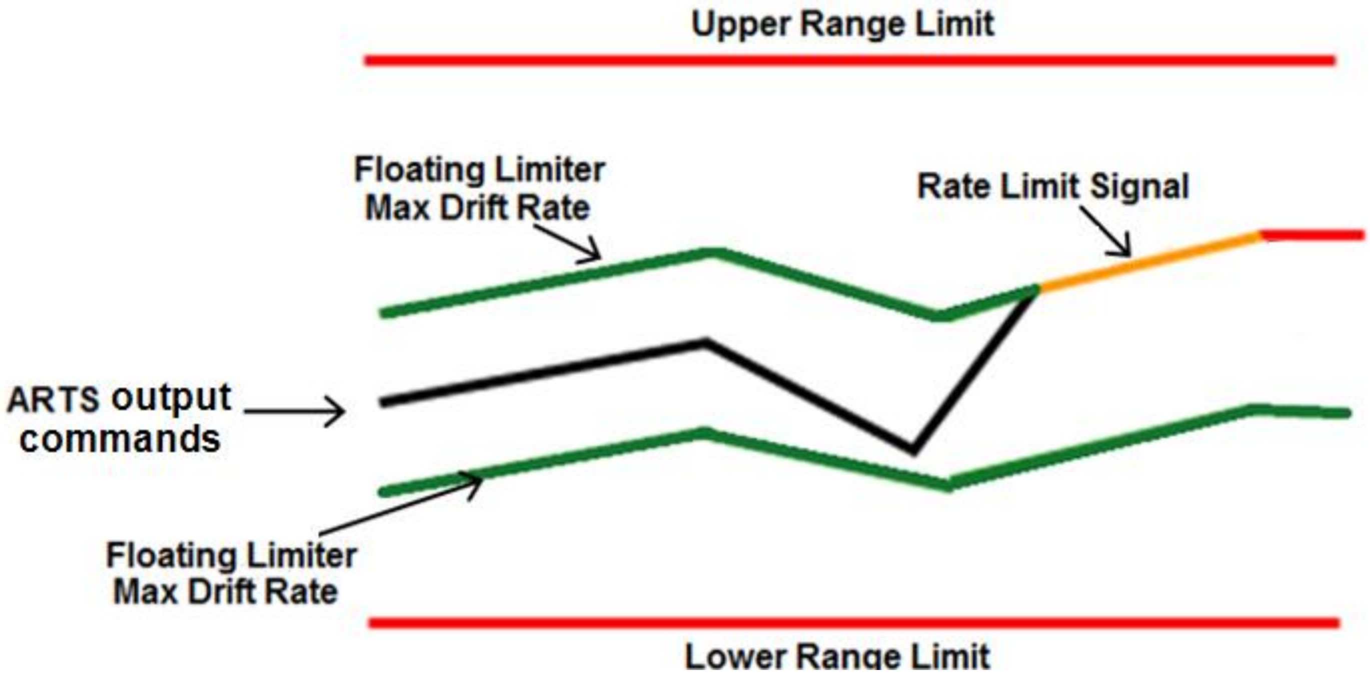
- “Class B” envelope - ensure within load limits
- Automatic disengage limits bound the envelope



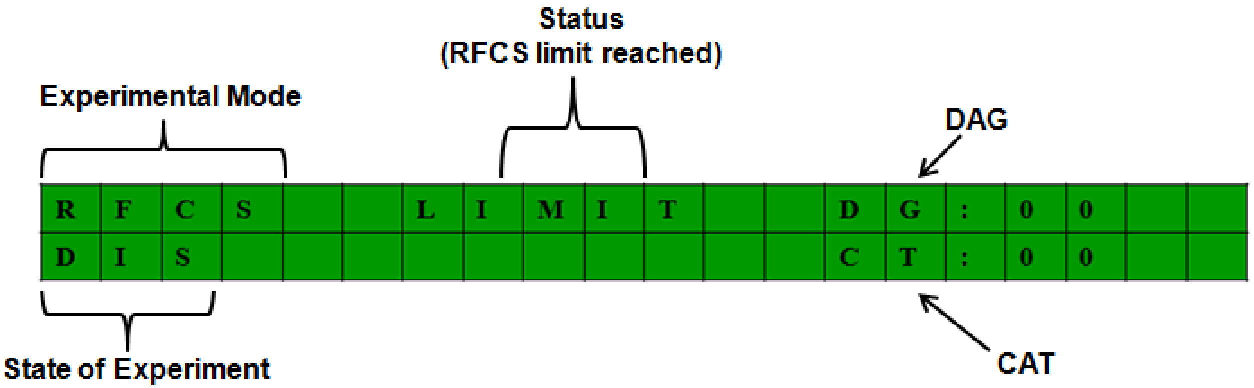
Eliminate unnecessary risk

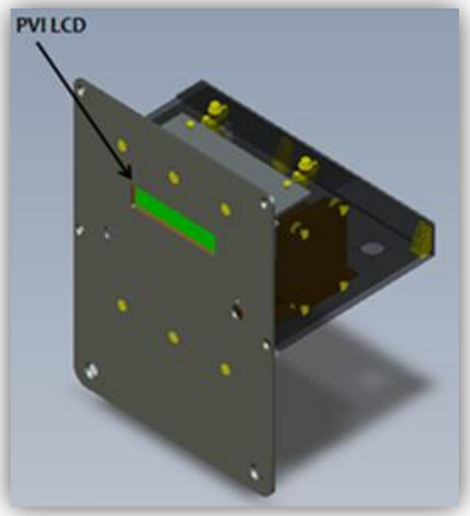
Risk Mitigation – Design
ARTS

- NASA Dryden developed ARTS IV "floating limiter"
  - auto disengagement tool



Risk Mitigation – Design
Pilot-Vehicle Interface (PVI)





- Hard to view & decipher

Consider iterative checkouts to confirm or improve human factor characteristics throughout project development

Risk Mitigation – Documentation
test card design

Consider incorporating cadence metric to assess test readiness

F-18 #853 - FAST		FLT #:	DATE:

Flight Block: RFCS Primary

Verify Card:

Flight Condition 6
HI : 25,000 FEET
MI: 0.58M ±0.02 M

DAG 0 CAT 9
Right Stab Failure

Control Room Checks

			Control Room Checks
A.	Straight & Level (FC6)		
	1. DDI – ENTER 'C-B-B'	*Verify DDI Entry*	*Systems*
	2. DDI – ENTER 'A '(Arm)	*Verify DAG and CAT*	*Systems*
	3. Engage RFCS		
	4. Initiate Failure		*Controls*
B.	Dynamics & Loads	*Record Pilot Comments*	
	1. Gentle Maneuvering		
	2. Doublets (3-axes)		
	3. Freq Sweeps (3-axes)		
	4. Pitch Capture +10 deg		
	5. Bank Captures: ±30 deg		
	6. Half-stick 360 Rolls		
	7. 2½ g Wind-up Turns		
C.	Disengage		

Risk Mitigation – Simulation

- Include control room personnel, as appropriate

Helps bridge flight expectations
(anticipated dialogue, cross-verification time)

- Test beyond the test point!

Unanticipated human-algorithm interactions
found in flight during test-point setup

Flight Test Approach

RFCS Primary

Research laws matched simulation predictions

RFCS/ARTS & ARTS Primary

Proper RFCS-ARTS communication	No excessive induced time delays

ARTS Primary

Nonlinear Dynamic Inversion (NDI) • Closed-loop; non-adaptive	Model Reference Adaptive Controller (MRAC)

Model Reference Adaptive Controller
Goals

1. Appropriate complexity
   - 3 modes complexity modes available
   - handling qualities assessment

2. Pilot interaction with adaptive controller
   - ability to freeze adaptation
   - handling qualities assessment

Model Reference Adaptive Controller flight test results

- Increased adaptive controller complexity:
  - adversely impacted pilot performance
  - yet improved dynamics similar to un-failed aircraft

Piloted, full-scale flight testing validates predictions & identifies unexpected tendencies

Lessons Learned

1. Design-out unnecessary risk to prevent excessive mitigation management during flight
2. Consider iterative checkouts to confirm or improve human factor characteristics
3. Consider the total flight test profile to uncover unanticipated human-algorithm interactions
4. Consider test card cadence as a metric to assess test readiness
5. Full-scale flight test is critical to development, maturation, and acceptance of adaptive control laws for operational use

Conclusion

Date	Test Type
Mar – April 2010	RFCS Primary – ground test + 3 flights
July – Aug 2010	RFCS/ARTS – ground test + 1 flights
Aug 2010	ARTS Primary - 1 flight
Sept – Oct 2010	NDI – ground test + 5 flights
Dec 2010 – Jan 2011	MRAC – ground test + 11 flights

Varied risk mitigations throughout a project lifecycle *can* support aggressive yet successful flight test