USAF Mode S Monitoring

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14 June 2011

*This work is sponsored by the United States Air Force under Air Force contract #FA8721-05-C-0002. Opinions, interpretations, recommendations, and conclusions are those of the author and are not necessarily endorsed by the United States Government.

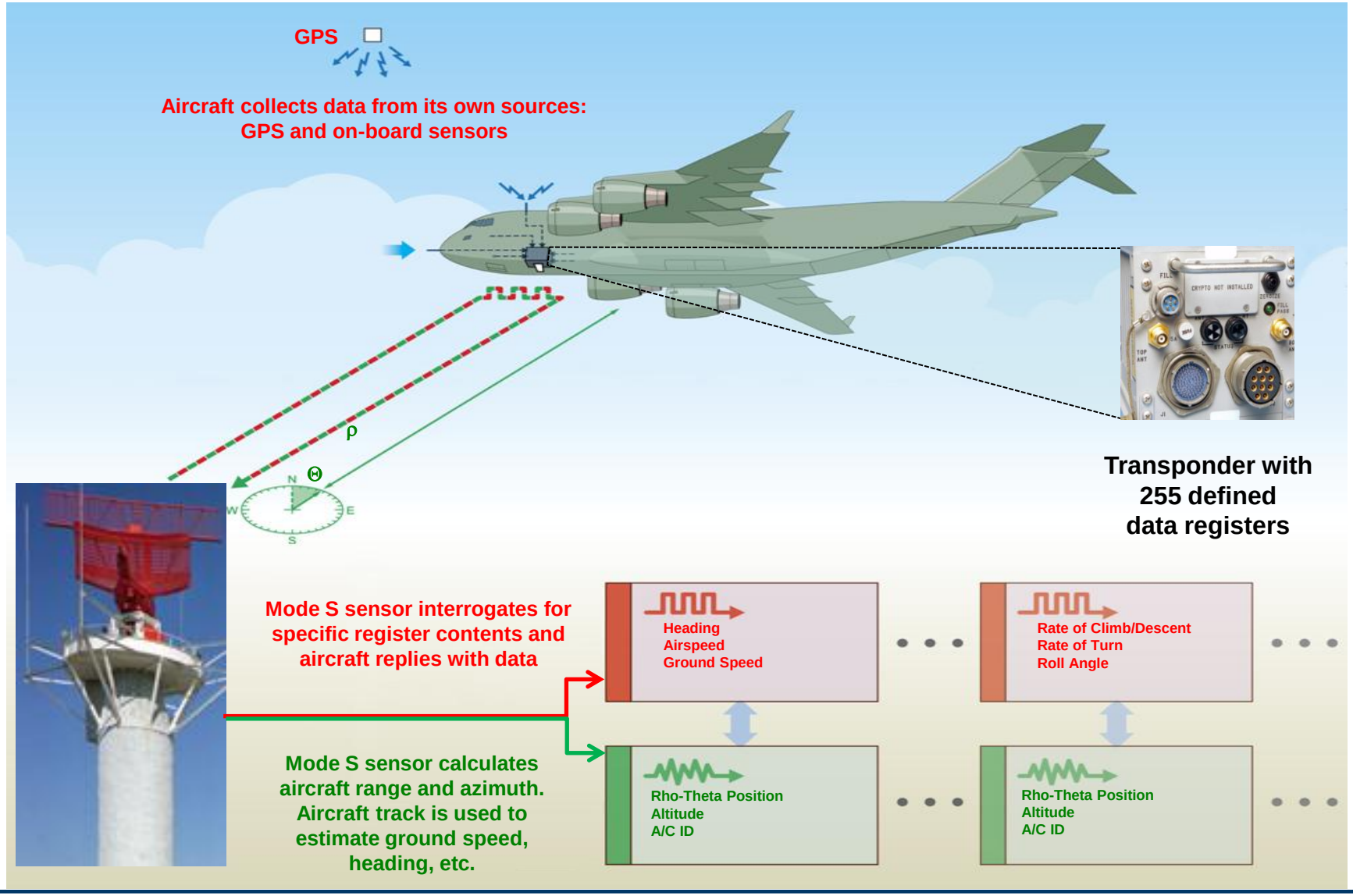
Outline

- USAF Mode S Monitoring – Background and Goals
- Elementary and Enhanced Surveillance (ELS/EHS) Monitoring
  - Mode S Surveillance and ELS/EHS Overview
  - Surveillance and Data Acquisition
  - Analysis of ELS/EHS Data
- Automated Fleet Monitoring System
  - Daily Traffic Summary
  - Fleet Equipage Statistics
  - Aircraft Specific Validation Reports
- Comm-B Data Selector ("BDS") Register Extraction Issue
- Summary

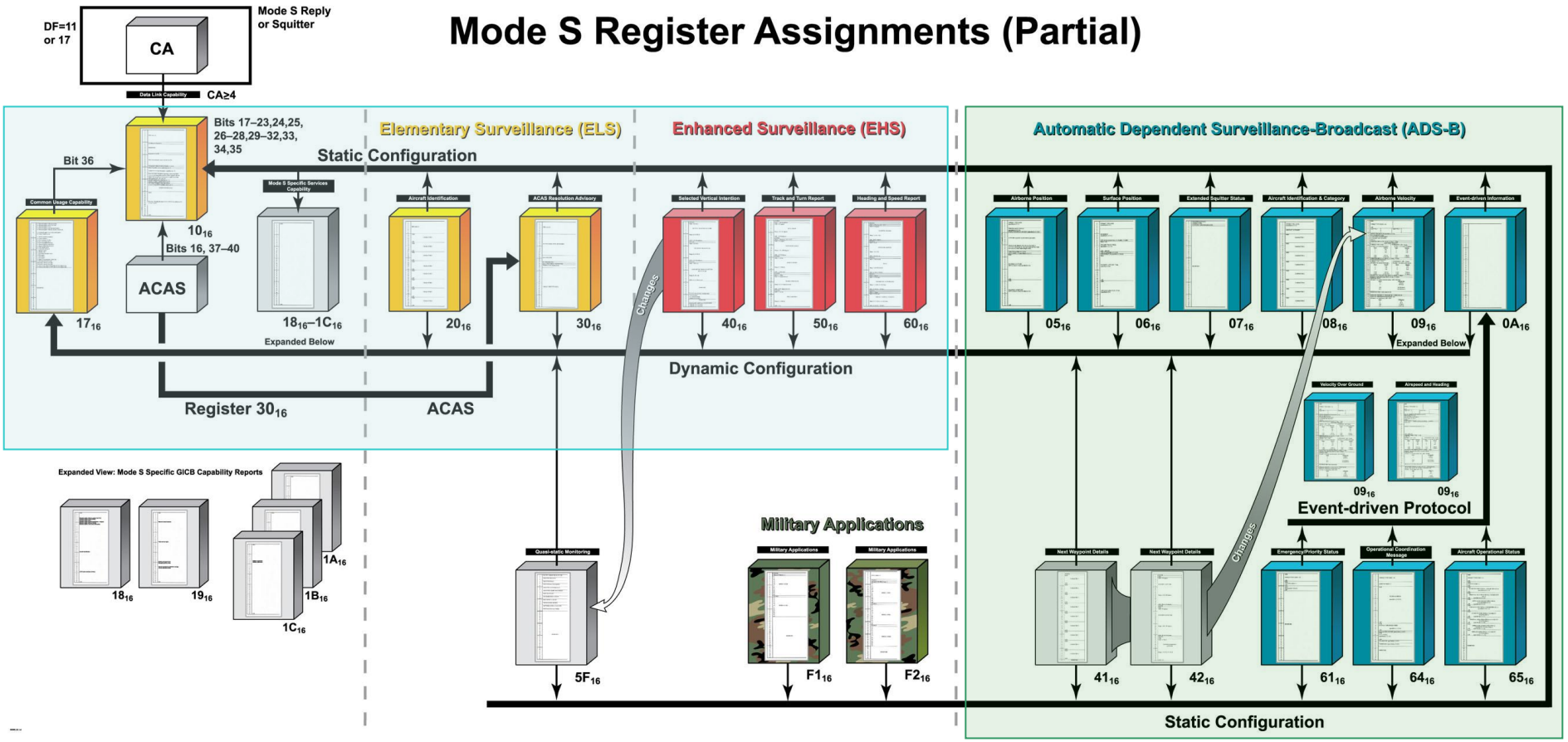
USAF Fleet Monitoring Goals and Approach

- **Sponsorship:**
  - **Aerospace Management Systems Division**
    USAF Electronic Systems Center, Hanscom AFB
- **Goal: Ensure US Military aircraft access to civilian airspace**
  - **Focus on Elementary and Enhanced Surveillance (ELS/EHS)**
  - **Determine validity of downlinked ELS and EHS data**
  - **Alert ESC of US Military aircraft that provide data inconsistent with the physical state of the aircraft**
  - **Characterize US Military fleet's rate of compliance**
- **Approach: Examine ELS/EHS data for aircraft in flight**
  - **Obtain ELS and EHS data from aircraft in a dynamic flight environment to confirm ELS/EHS capability**
  - **Confirm availability of ELS/EHS registers and accuracy of data**
  - **Determine compliance of individual US DoD aircraft**
  - **Provide statistical summaries of fleet equipage**

Mode S Surveillance and ELS/EHS Register Extraction



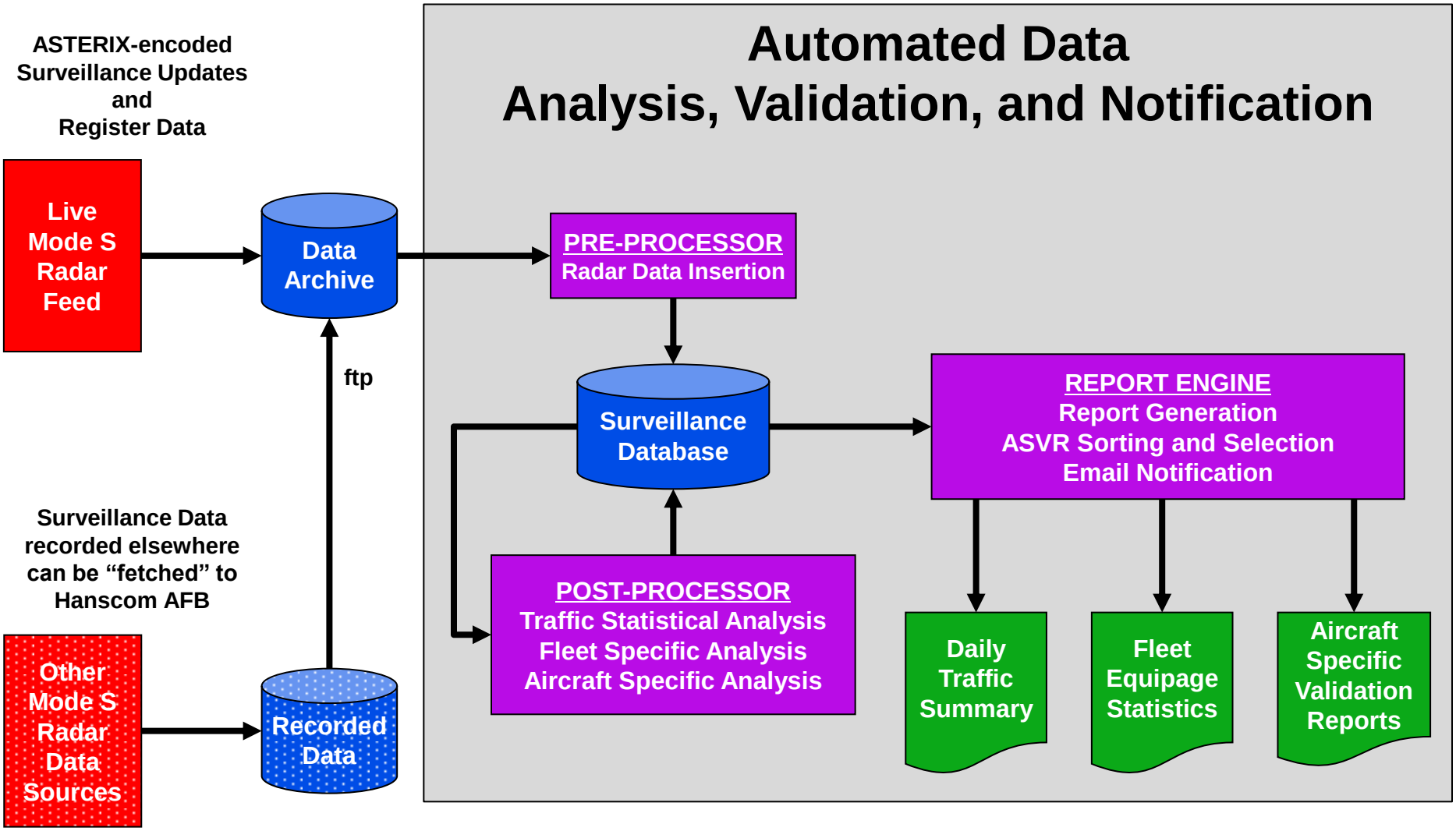
Mode S Registers
ELS, EHS, and ADS-B



- European Mode S ELS/EHS mandates have been in effect for all aircraft since 31 March 2009
- FAA has issued an ADS-B "out" mandate for 2020
- Europe has a mandate for ADS-B "out" - "forward fit" in 2015, "retro-fit" in 2017, State in 2019

USAF Mode S Monitoring

Data Acquisition and Analysis System Architecture

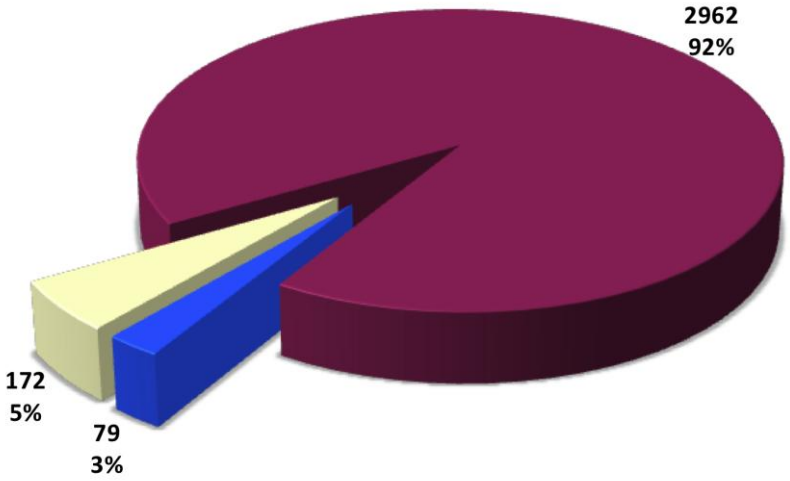


ELS/EHS Monitoring

- **Data from Neunkircher-Höhe (NEUS), 3 Nov 2010**

Daily Traffic Summary

Data from Neunkircher-Höhe (NEUS) 3 Nov 2010



Counts of Unique Mode S Addresses by Fleet Segment

US Military	79
US Civilian	172
Non-US	2,962
Total:	3,213

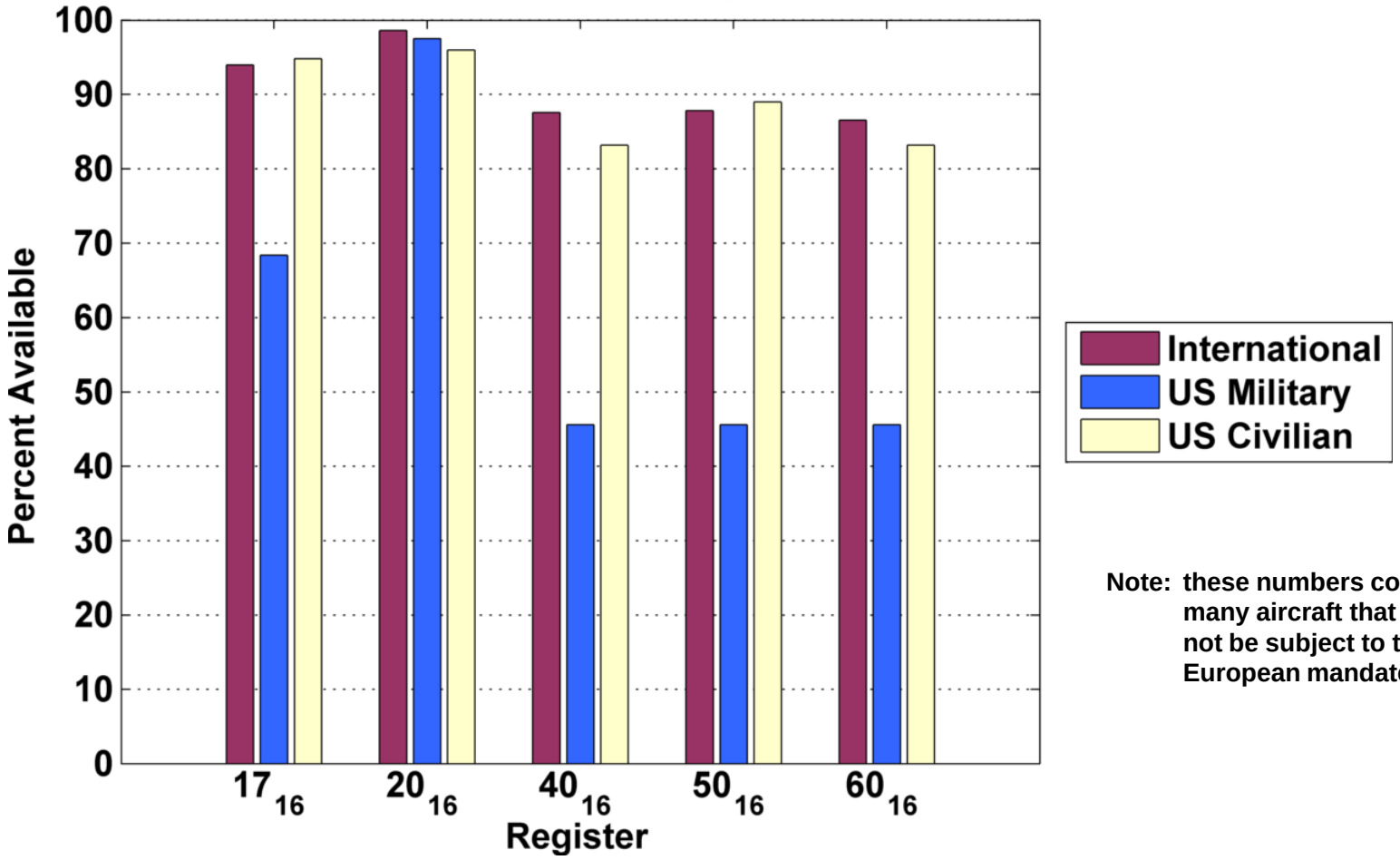
Report Segment

Fleet Equipage Statistics

- Report on data available from fleet segments
  - US Military
  - US Civilian
  - Non-US (aka “International”)

- Report on data provided by radar
  - Analysis of registers and data, not on reporting capabilities
  - Rates of fleet segments providing ELS and EHS data
  - Normalized by percentages of equipage rates
    - Percentages of fleet segments providing registers
    - Percentages of filled data fields in registers
  - Primary focus on EHS Registers
    - 40_{16} – Selected Vertical Intent
    - 50_{16} – Track and Turn Report
    - 60_{16} – Heading and Speed Report

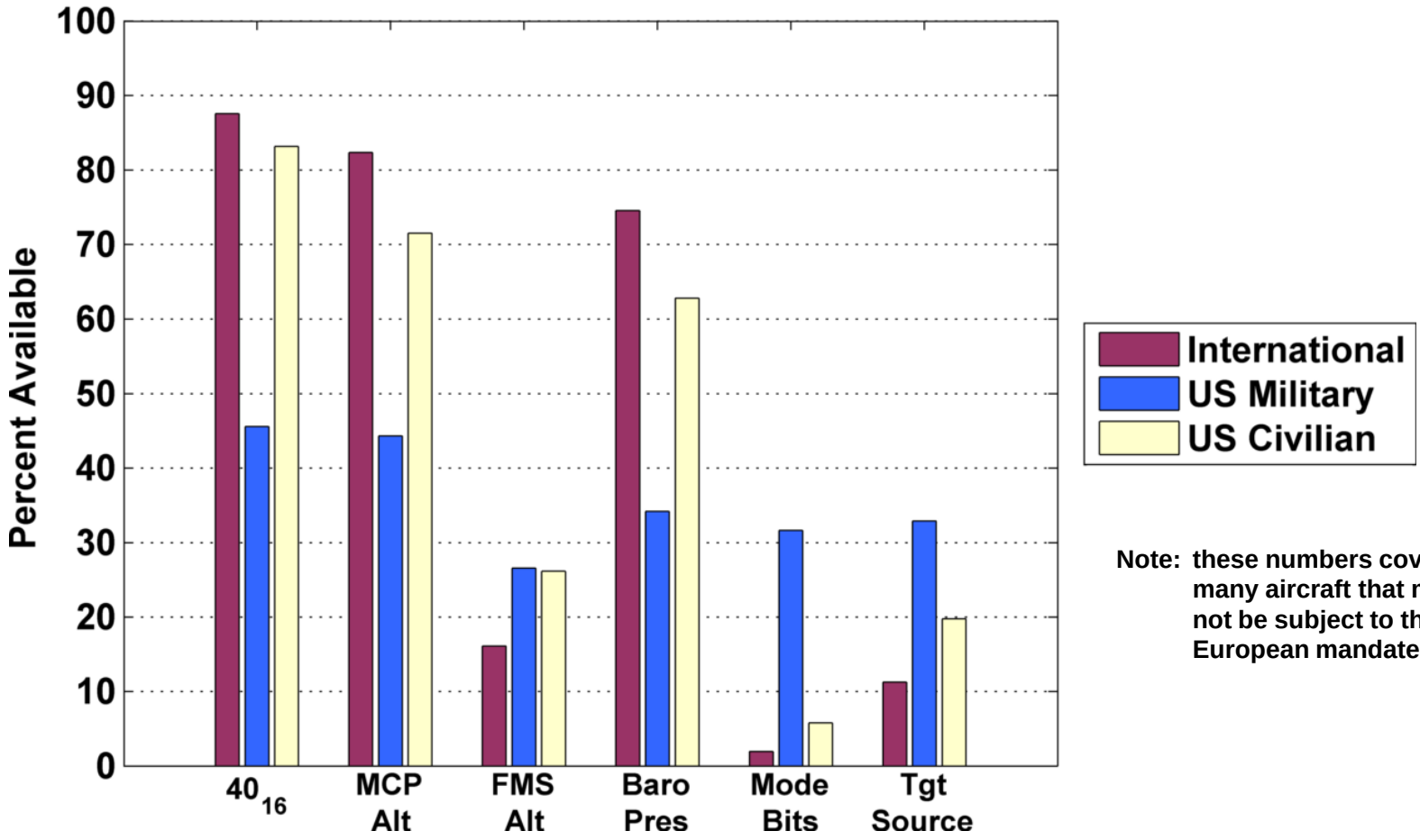
ELS/EHS Register Availability



Note: these numbers cover many aircraft that may not be subject to the European mandates

* "Percent Available" refers to the percent of that traffic category's fleet observed in the current reporting period

Register (40_{16}) Field Availability
Selected Vertical Intent



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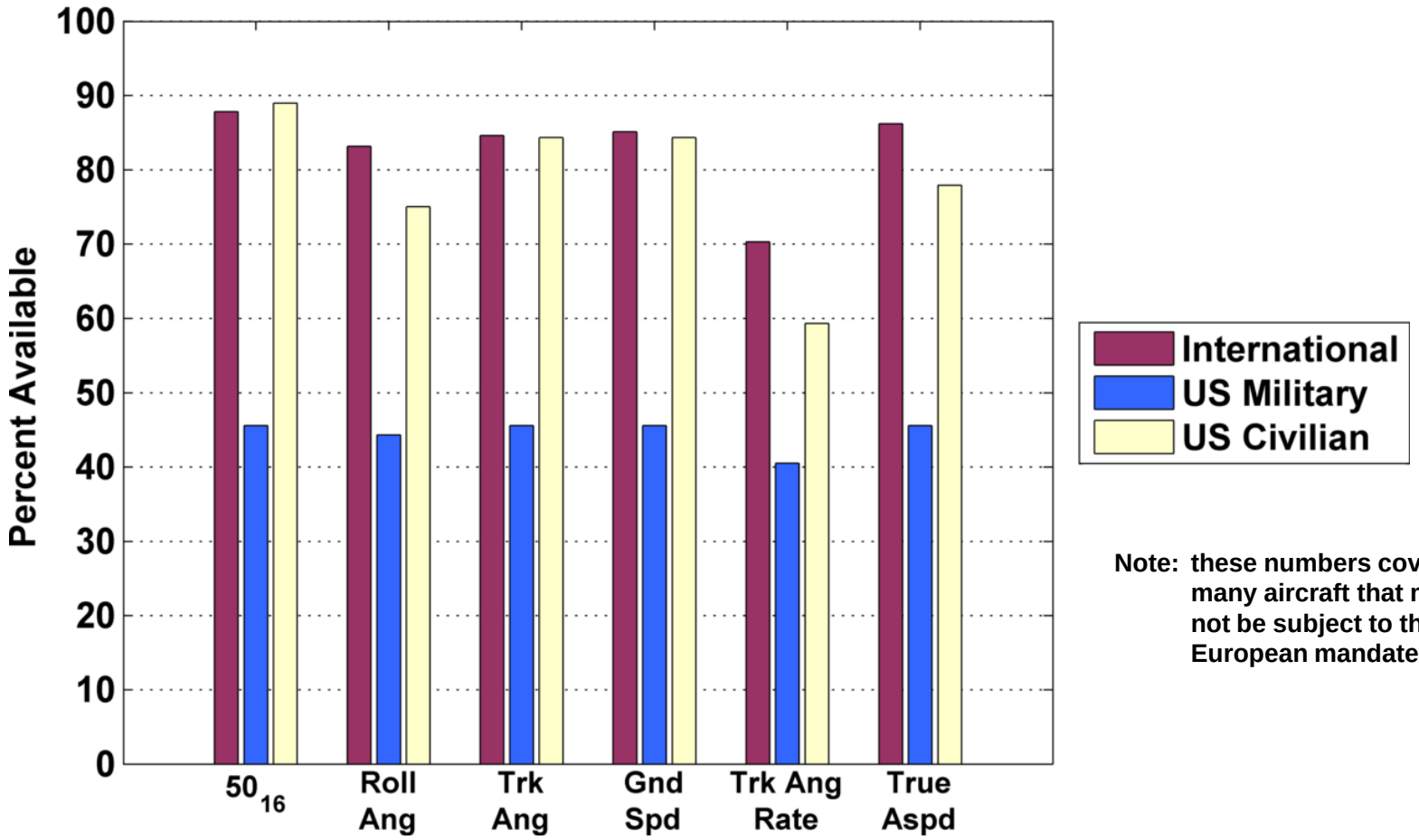
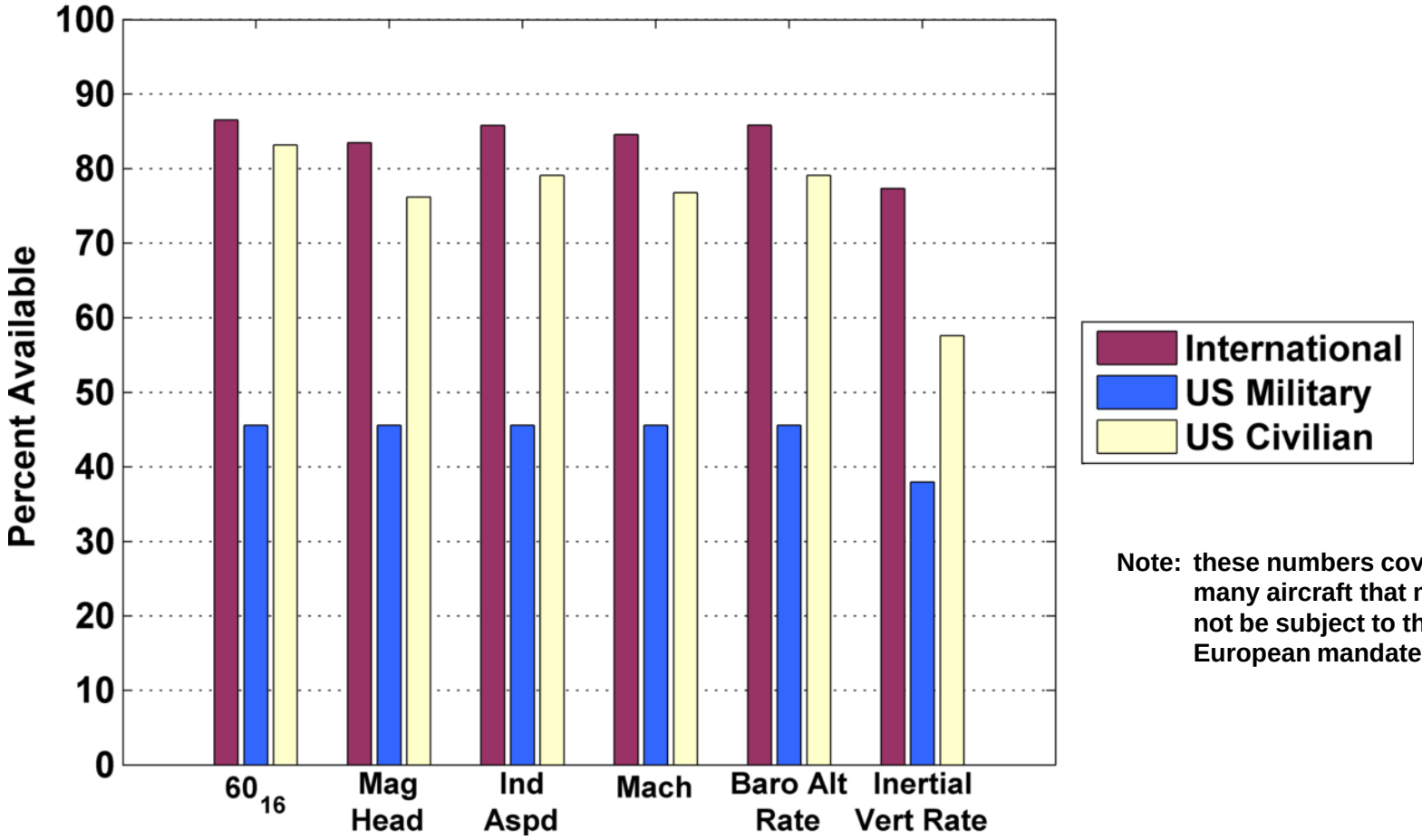
Register (50_{16}) Field Availability
Track and Turn Report



Note: these numbers cover many aircraft that may not be subject to the European mandates

* "Percent Available" refers to the percent of that traffic category's fleet observed in the current reporting period

Register (60_{16}) Field Availability
Heading and Speed Report



Note: these numbers cover many aircraft that may not be subject to the European mandates

* "Percent Available" refers to the percent of that traffic category's fleet observed in the current reporting period

Fleet Equipage Statistics
Additional Notes

- **US Military equipage rates lag other fleet segments**
  - **US Military fleet includes many aircraft exempted from the mandates**
  - **Helicopters and special purpose aircraft included**
  - **Constraining the US Military fleet to those aircraft that are subject to the mandates**
    - **Increases the US Military equipage rate to 73%**
    - **More in line with the other two fleet segments**
- **Trends for all fleet indicate improving rates for all**

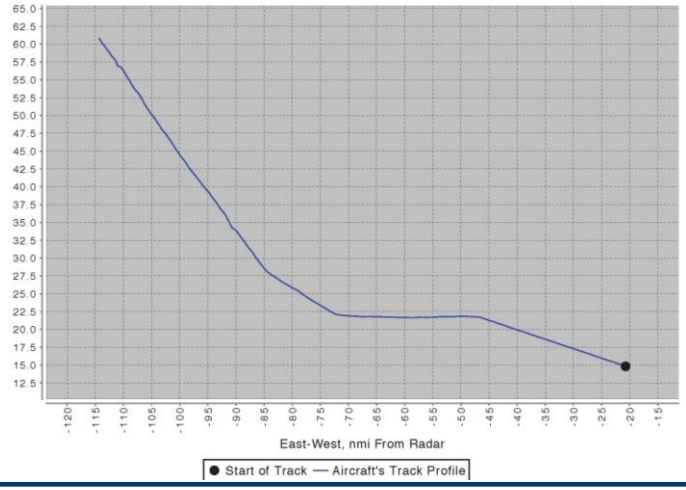
Aircraft Specific Validation Report (ASVR)

- Analysis of one track segment of aircraft's flight per day
  - Each flight may produce multiple track segments
  - Track segments are rated by data availability
  - "Best" track is basis of analysis
- Summary of track parameters
  - Surveillance source
  - Aircraft identification
  - Date, time, and duration of track
  - Counts of surveillance updates and ELS/EHS registers
- Analysis of downlinked data items
  - Reference track derived from surveillance updates
  - Test intervals from reference track and test thresholds
  - Downlinked data items compared against test intervals
- Rates of valid data reported in ASVR

Aircraft Specific Validation Report
Track Summary

- **Summary of track parameters**
- **Aircraft and surveillance IDs (not listed here)**
- **Plots of aircraft state data**

- **eg: X-Y track plot**



Flight Summary

Duration:	00:20:21.539
Number of Surveillance Reports:	106
X Extent (With Respect To Radar)	-114.34 to -20.72 nmi
Y Extent (With Respect To Radar)	14.82 to 60.79 nmi
Reported Altitude Extent:	7100.00 to 28000.00 ft

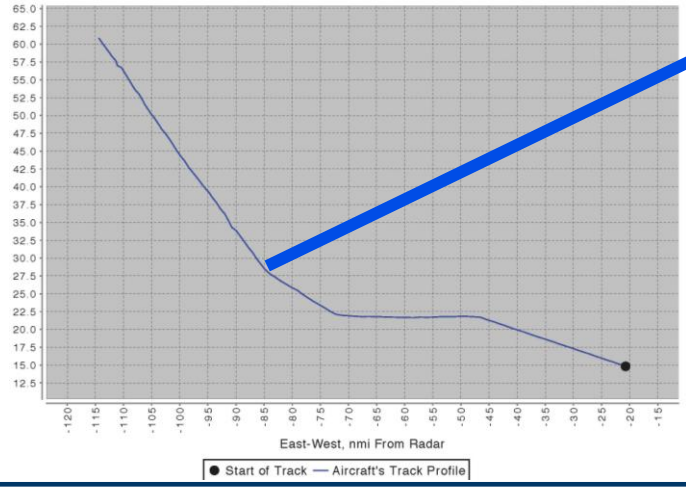
Validation Data Availability

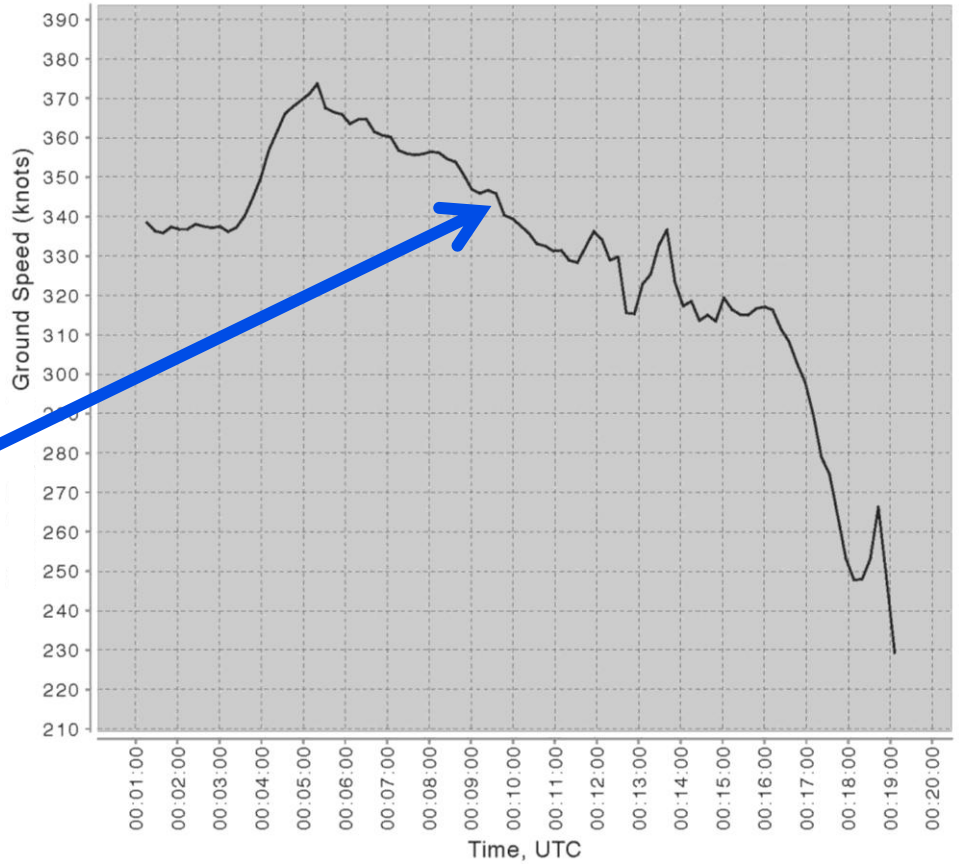
ELS Registers Provided:	20 (implied)
EHS Registers Provided:	50
Other Registers Provided:	51

Aircraft Specific Validation Report

Data Estimates from Reference Track

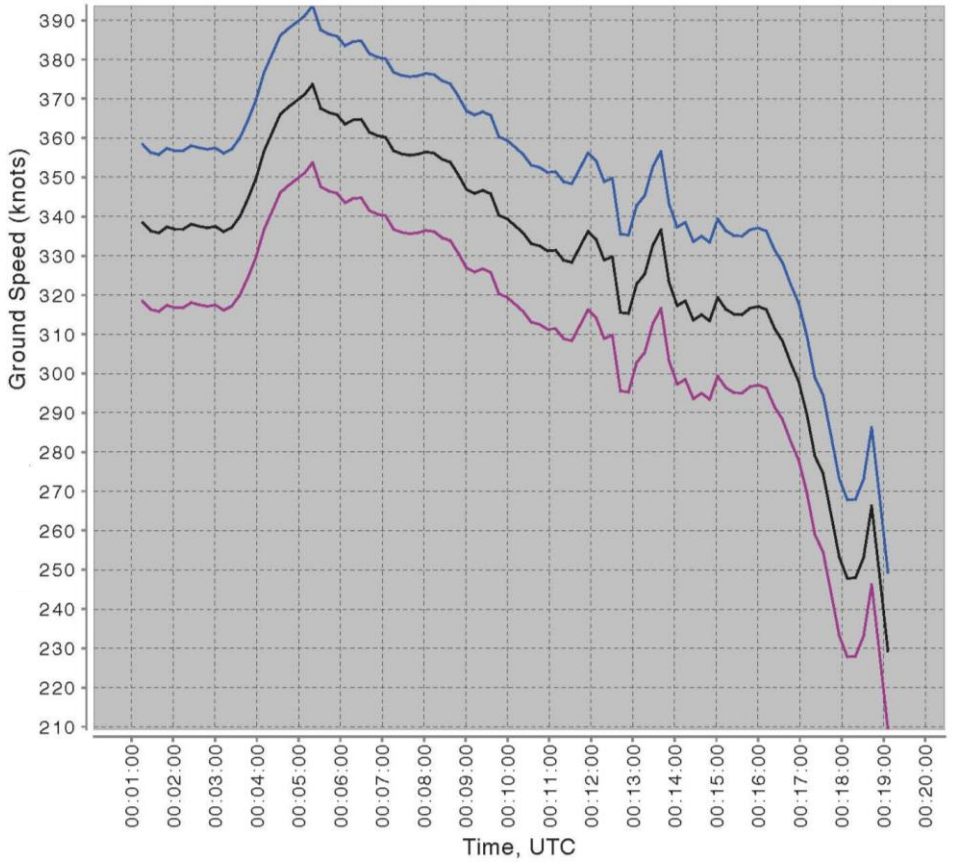
- **Ground Speed example**
- **Data item estimates**
  - **X-Y position data derived from surveillance updates in reference track**
  - **Apply 7-point smoother**
  - **Speed estimates from smoothed data**





Aircraft Specific Validation Report
Validation Test Intervals

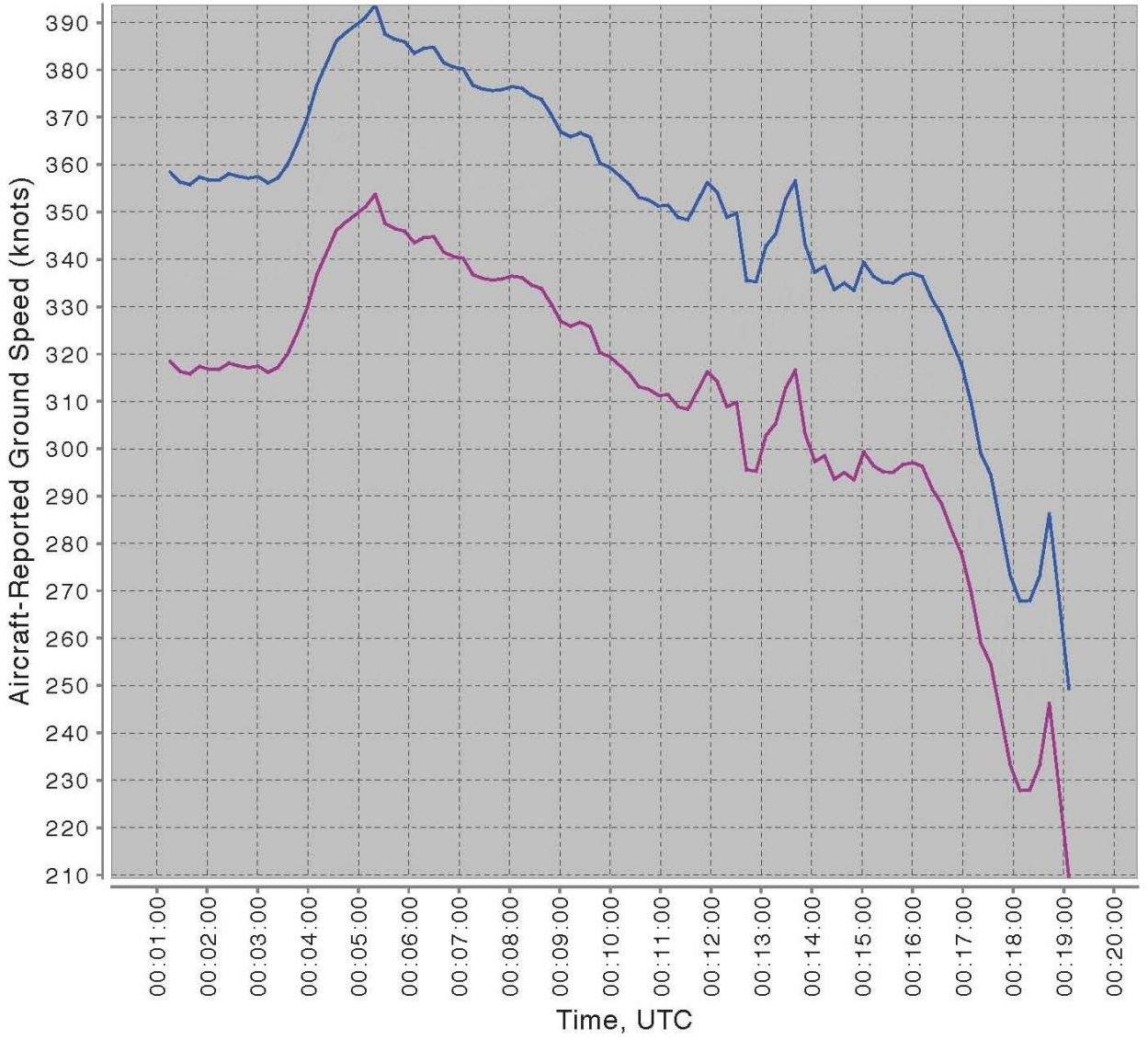
- **Ground Speed example (Register 5,0)**
- **Upper & Lower bounds**
  - **Test Threshold: 20 Kts**
  - **Threshold added to each ground speed estimate to compute upper bound (blue curve)**
  - **Threshold subtracted to compute lower bound (magenta curve)**
  - **Range between upper and lower bounds comprise test intervals**



Aircraft Specific Validation Report

Ground Speed validation upper and lower bounds

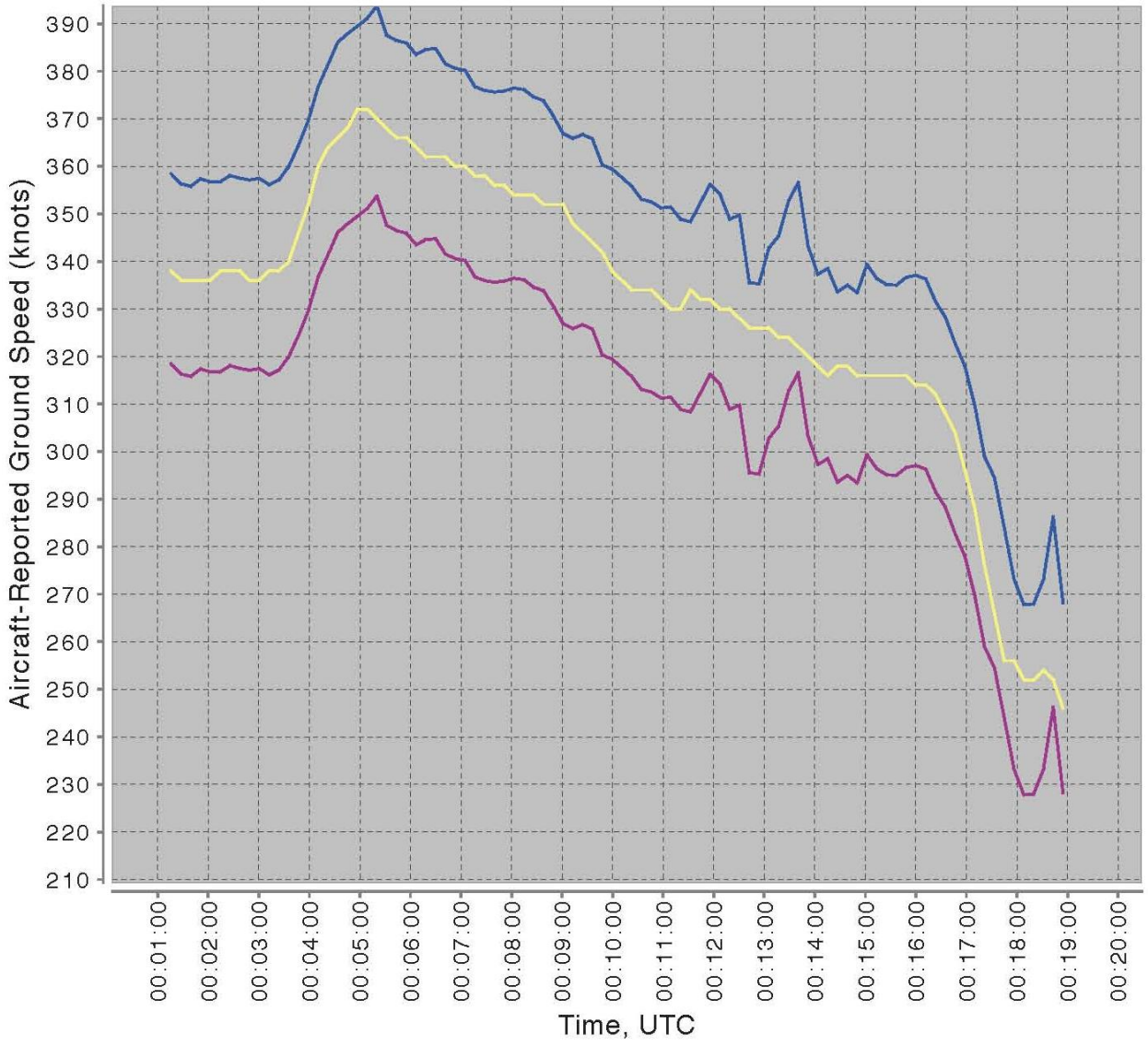
- **Test limits**
- **Upper and lower bounds based on reference track and thresholds (20 Kts)**



Aircraft Specific Validation Report

Downlinked Ground Speed with Test Bounds

- **Downlinked data from EHS Reg 5,0 plotted with its test limits (yellow curve)**
- **Downlinked data fall within test limits in this example**
- **Validation rate 100%**
- **Process repeated for all downlinked aircraft state data**



Aircraft Specific Validation Report

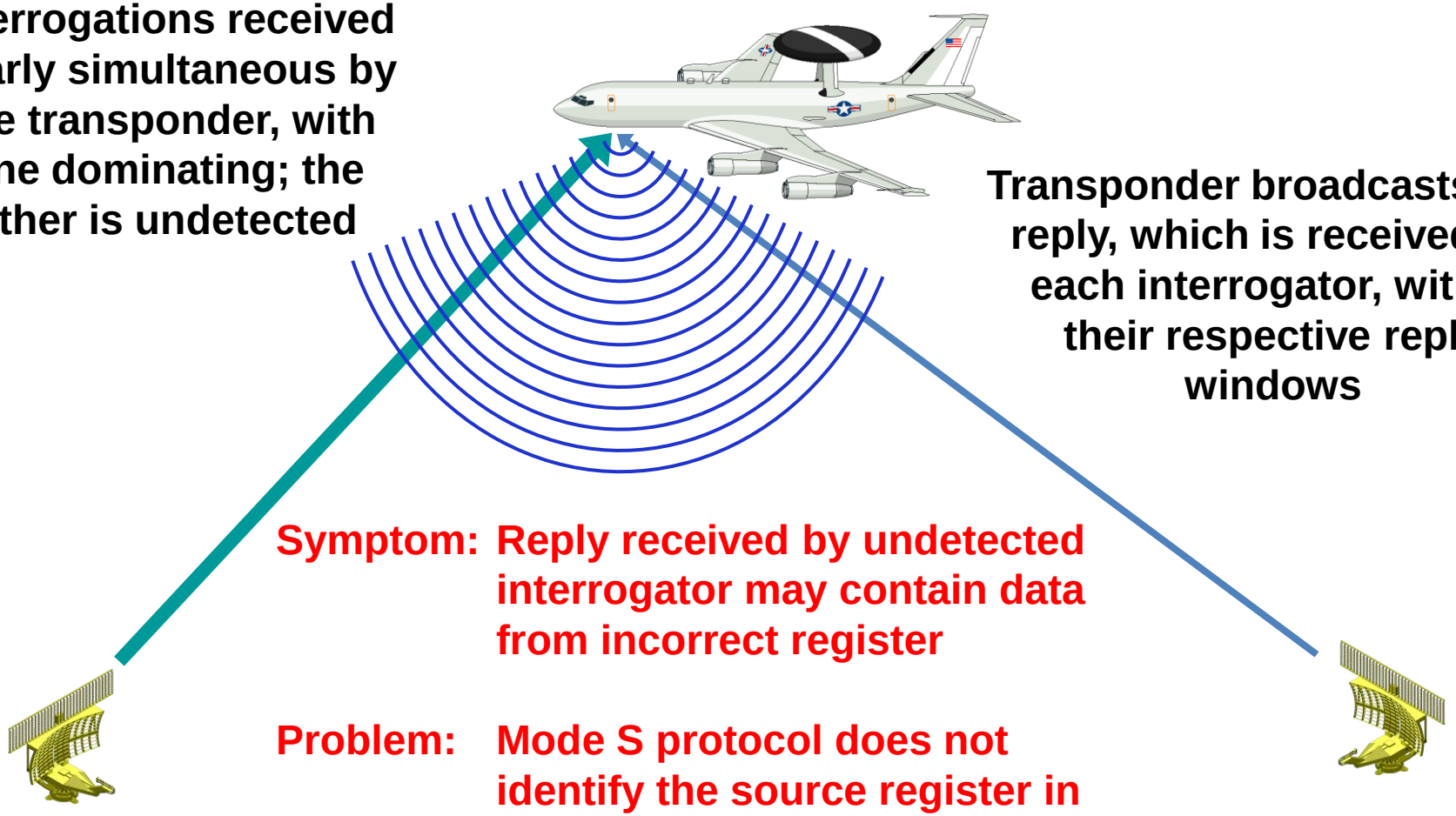
Validation Percentages

50_{16}	ROLL ANGLE STATUS SET	0.00
	ROLL ANGLE	N/A
	TRUE TRACK ANGLE STATUS SET	100.00
	TRUE TRACK ANGLE	94.62
	GROUND SPEED STATUS SET	100.00
	GROUND SPEED	100.00
	TRACK ANGLE RATE STATUS SET	0.00
	TRACK ANGLE RATE	N/A
	TRUE AIRSPEED STATUS SET	100.00
	TRUE AIRSPEED	100.00

ASVRs provided to USAF for use in compliance determination

Surveillance Issue Affecting Validation
"BDS Swap"

Interrogations received nearly simultaneous by the transponder, with one dominating; the other is undetected



Transponder broadcasts one reply, which is received by each interrogator, within their respective reply windows

Symptom: **Reply received by undetected interrogator may contain data from incorrect register**

Problem: **Mode S protocol does not identify the source register in the reply**

Dominant interrogator receives correct reply

Undetected interrogator receives the same reply as the dominant interrogator

BDS Swap Data Sample

- **Short sample of downlinked registers 4,0, 5,0, and 6,0**
- **Contents of 4,0 and 5,0 at time 15:32:34 are identical**

Date	Time	Mode S	Register	Contents	
06/04/09	15:32:28	400568	60	E6BA552F21842E	
06/04/09	15:32:28	400568	40	BA980030AA0180	
06/04/09	15:32:28	400568	50	FFDC89347FFCE1	
06/04/09	15:32:34	400568	60	E6BA552F216C2C	
06/04/09	15:32:34	400568	40	BF480030AA0180	Duplicate Content
06/04/09	15:32:34	400568	50	BF480030AA0180	Duplicate Content
06/04/09	15:32:47	400568	60	E6DA572FA17C2E	
06/04/09	15:32:47	400568	50	801C87353FFCE3	
06/04/09	15:32:47	400568	40	BE800030AA0180	

BDS Swap →

- **Registers 4,0 and 6,0 seem unaffected**
- **Register 5,0 contents at time 15:32:34 would require large aircraft accelerations:**

Time	Roll Angle	True Track Angle	Ground Speed	Track Angle Rate	True Airspeed
15:32:28	-0.352 deg	-78.047 deg	418 kts	-0.0313 deg/sec	450 kts
15:32:34	88.945 deg	N/A (-180.000 deg)	N/A (388 kts)	10.000 deg/sec	N/A (768 kts)
15:32:47	0.000 deg	-78.223 deg	424 kts	-0.0313 deg/sec	454 kts

BDS Swap Detection and Suppression

- **Important for both real time use and monitoring**
  - **Air Traffic Control**
    - **Conflict detection and alert, minimize false alarms**
    - **Managing airspace access**
  - **Monitoring**
    - **Proper detection of problems and corrections**
    - **Minimizing false alarms and unnecessary maintenance actions**

- **Trade-off between discarding good data versus using bad data**
  - **Discarding good data has little effect**
    - **Swap phenomenon typically a one-scan event**
    - **Data refreshed within seconds**
    - **ATC and automation conditioned to coast through data absence**
  - **Using incorrect data can mislead controllers and/or automation**
    - **Incorrect indications of changes in acceleration or flight path**
    - **Diminished acceptance of downlinked data by ATC**
    - **Automation can take multiple cycles to recover**

Responses to BDS Swaps

- **Surveillance-oriented solution**
  - **Duplicate register extractions on each scan**
    - **Multiple copies of register contents downlinked**
    - **Non-identical extractions are discarded**
  - **BDS Overlay**
    - **Extend Mode S protocol to overlay BDS code on ICAO address in reply**
    - **Reply errors cause address decoding error, so reply is discarded**

- **Automation-oriented solution**
  - **Reference surveillance comparison**
    - **Develop state vector based on reference surveillance**
    - **Compare register data against state vector**
    - **Discard data that do not match reference**
  - **Scan-to-scan comparison**
    - **Compare sequential instances of register data**
    - **Discard data that imply excessive accelerations**

Summary

- US Military Fleet Monitoring
  - Goal is to support USAF access to civilian airspace
  - Current focus is on validating data in ELS/EHS registers
- Automated System
  - Daily Traffic Summary
  - Fleet Equipage Statistics
  - Aircraft Specific Validation Reports
- Surveillance Issue – BDS Swaps
  - Incorrect data supplied for transponder register
  - Result of near-simultaneous interrogations
  - Variety of responses considered
    - Surveillance
    - Automation