CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Aeronautical Charting Forum
National Geospatial-Intelligence Agency
May 2, 2007

Analysis of Flight Management Systems (FMSs)

"FMC Field Observations Trial"

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CAASD

MITRE

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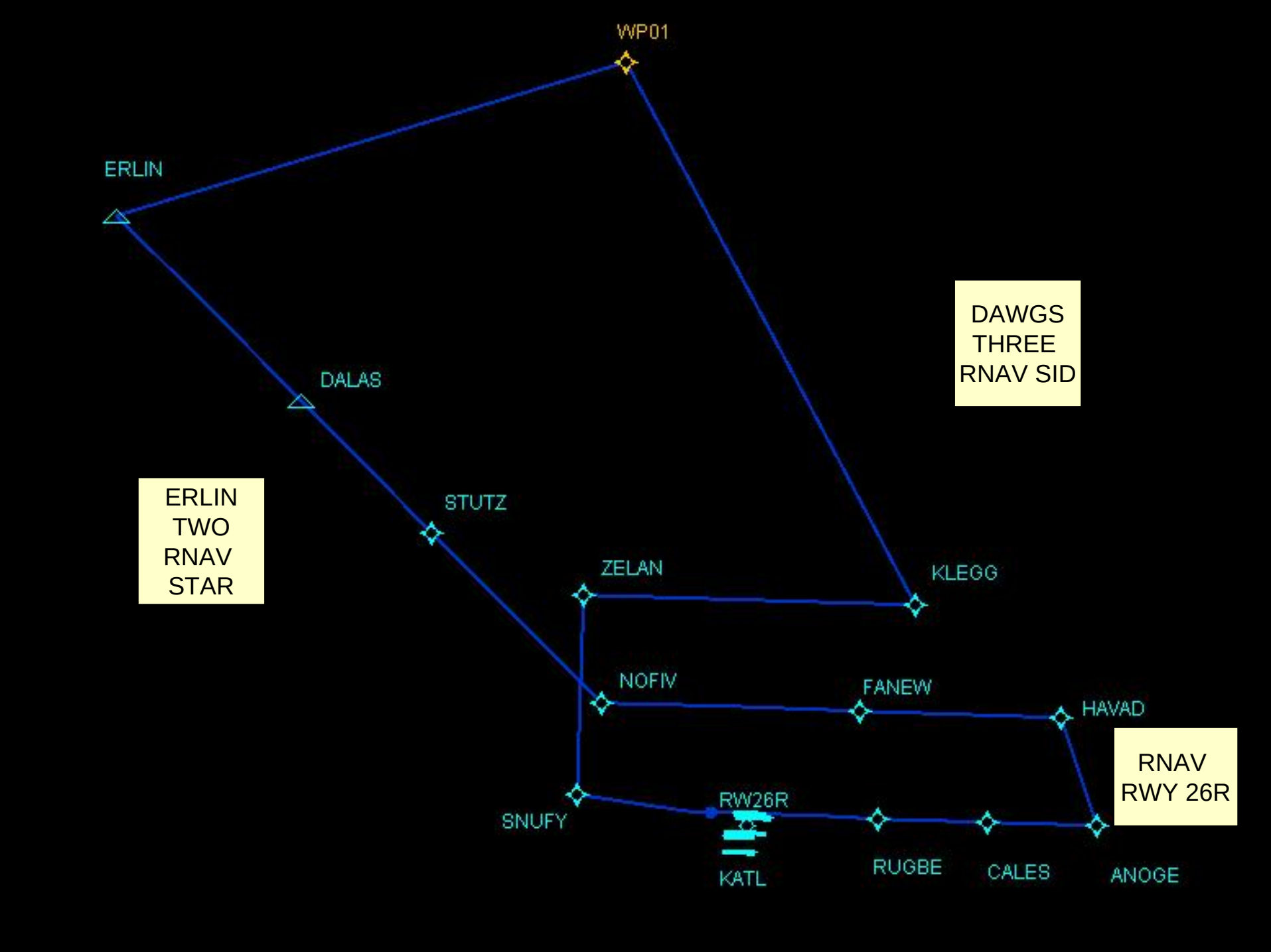
Test and Evaluation Method

- A short list of major “problems” encountered during RNAV implementations was compiled
- An route of flight was constructed using current RNAV procedures that contain examples of the problem areas
- The route contained various constraints and:
  - Departure climbing / accelerating turns with average and maximum course changes
  - Level segment with a turn at cruise altitude
  - Arrival / approach descending / decelerating turns with maximum and average angular extent
  - A missed approach with holding


WP01
ERLIN
DALAS
STUTZ
ZELAN
KLEGG
NOFIV
FANEW
HAVAD
SNUFY
RW26R
KATL
RUGBE
CALES
ANOGE
DAWGS THREE RNAV SID
ERLIN TWO RNAV STAR
RNAV RWY 26R

Manufacturers

- **Smiths Aerospace (MITRE in-house Test Bench)**
  - **B737-600 (U-10.5A)**
- **CMC Electronics (Canadian Marconi)**
  - **B747-200 (CMA-900/2014)**
- **Honeywell**
  - **Embraer 145 (NZ-2000)**
- **Universal**
  - **Cessna Citation II (UNS-1E SCN801.5)**
- **Rockwell Collins**
  - **CRJ-700 (FMC-4200)**
- **FAA Oklahoma City (AFS-440)**
  - **B737-800 (U-10.5A)**
- **Boeing (Honeywell)**
  - **Boeing 757-200, 767-300, 777-200, 747-400**
- **Thales Smiths**
  - **Airbus 320 (FMS2)**

Results Presentation

- The results are presented graphically for each system, with combined graphs showing the comparisons.
- Each system's performance was shown as a pair of tracks, with and without wind
  - For each track, the altitude, roll angle and ground speed were plotted vs along-track distance
    - This allows comparison of turn anticipation and speed performance
  - For three particular sections of the path (two turns and the hold) there are graphs of
    - Expanded scale for the above data and
    - Distance from flown path to the "stick" tracks

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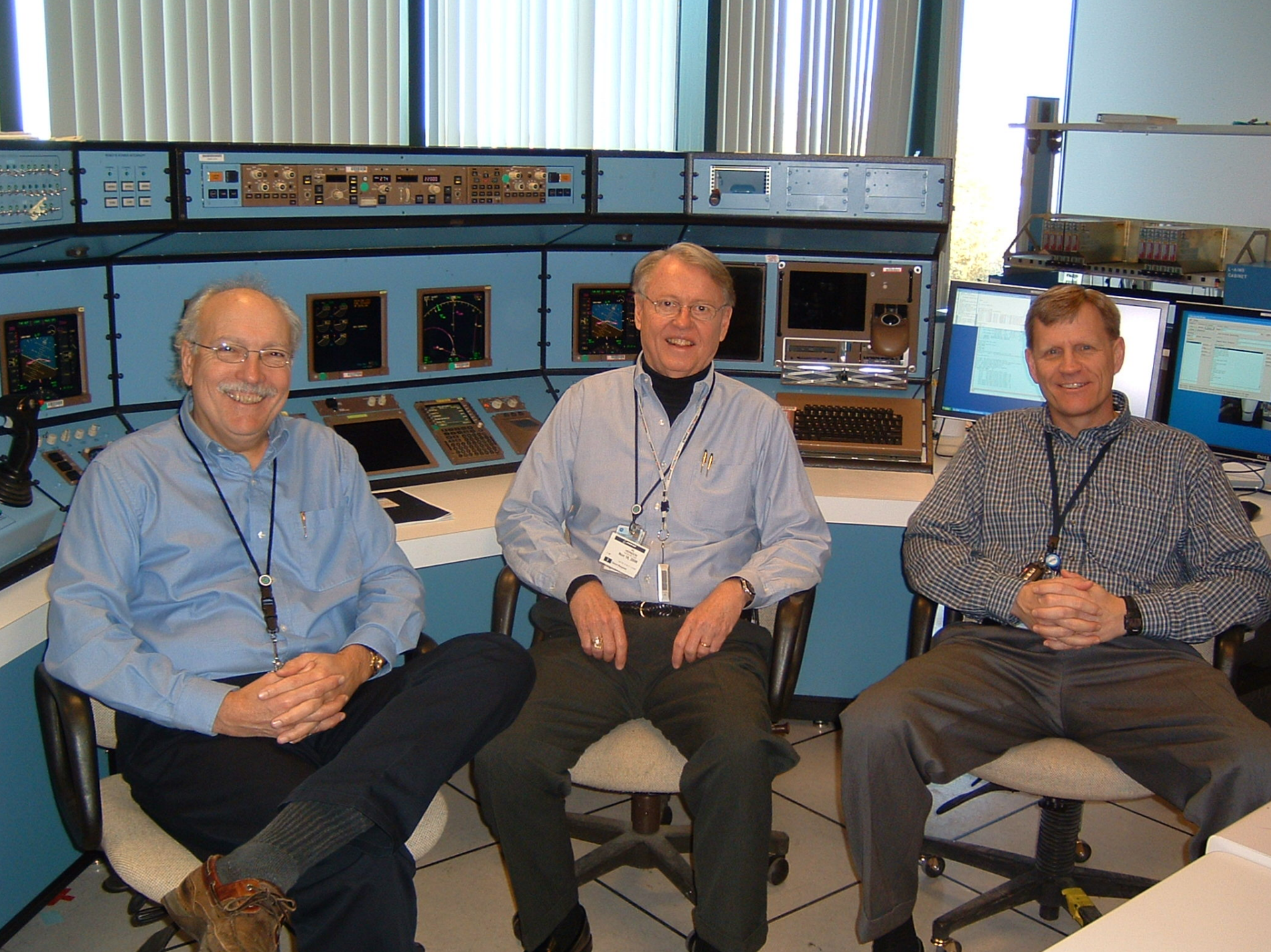
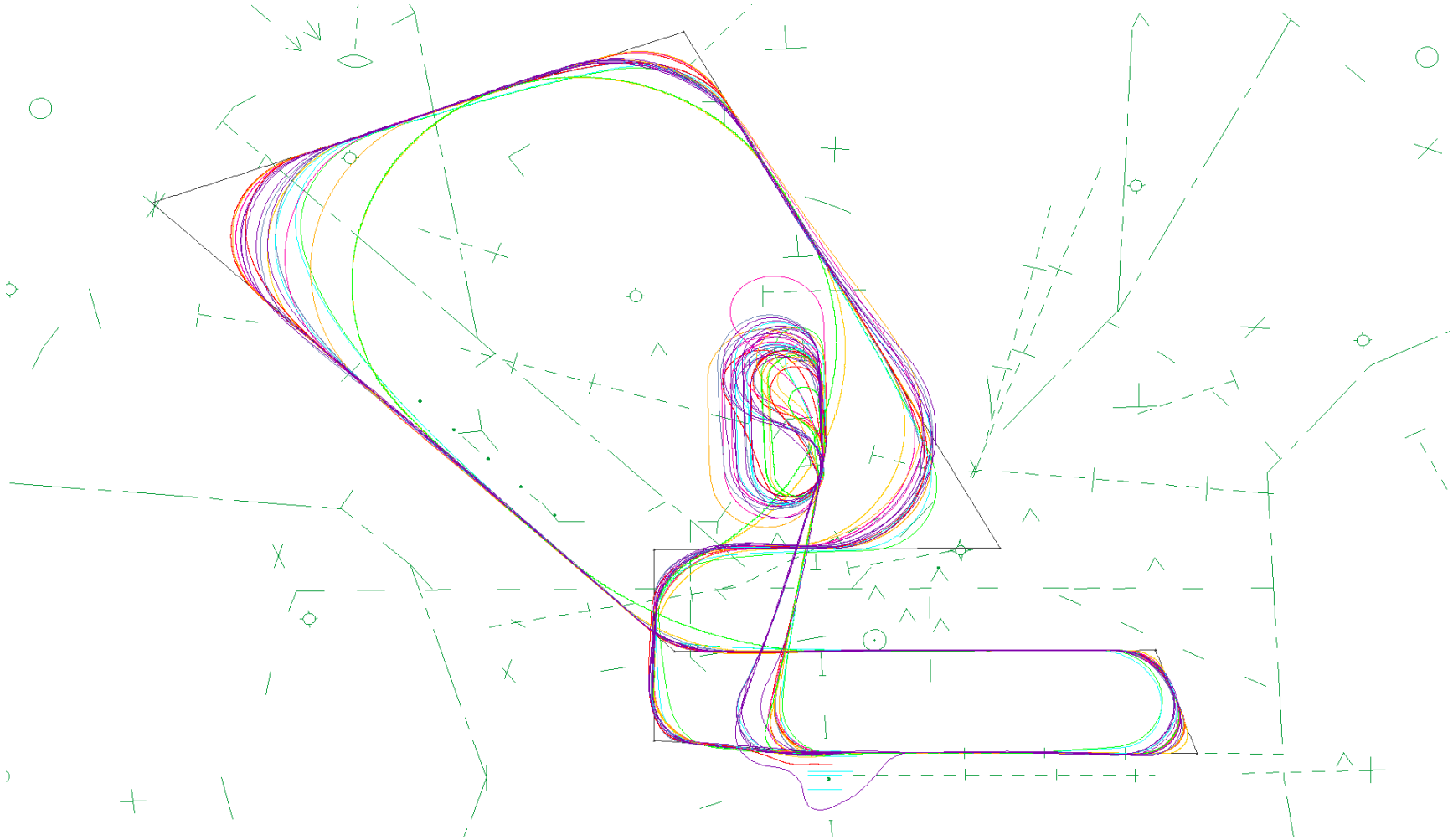
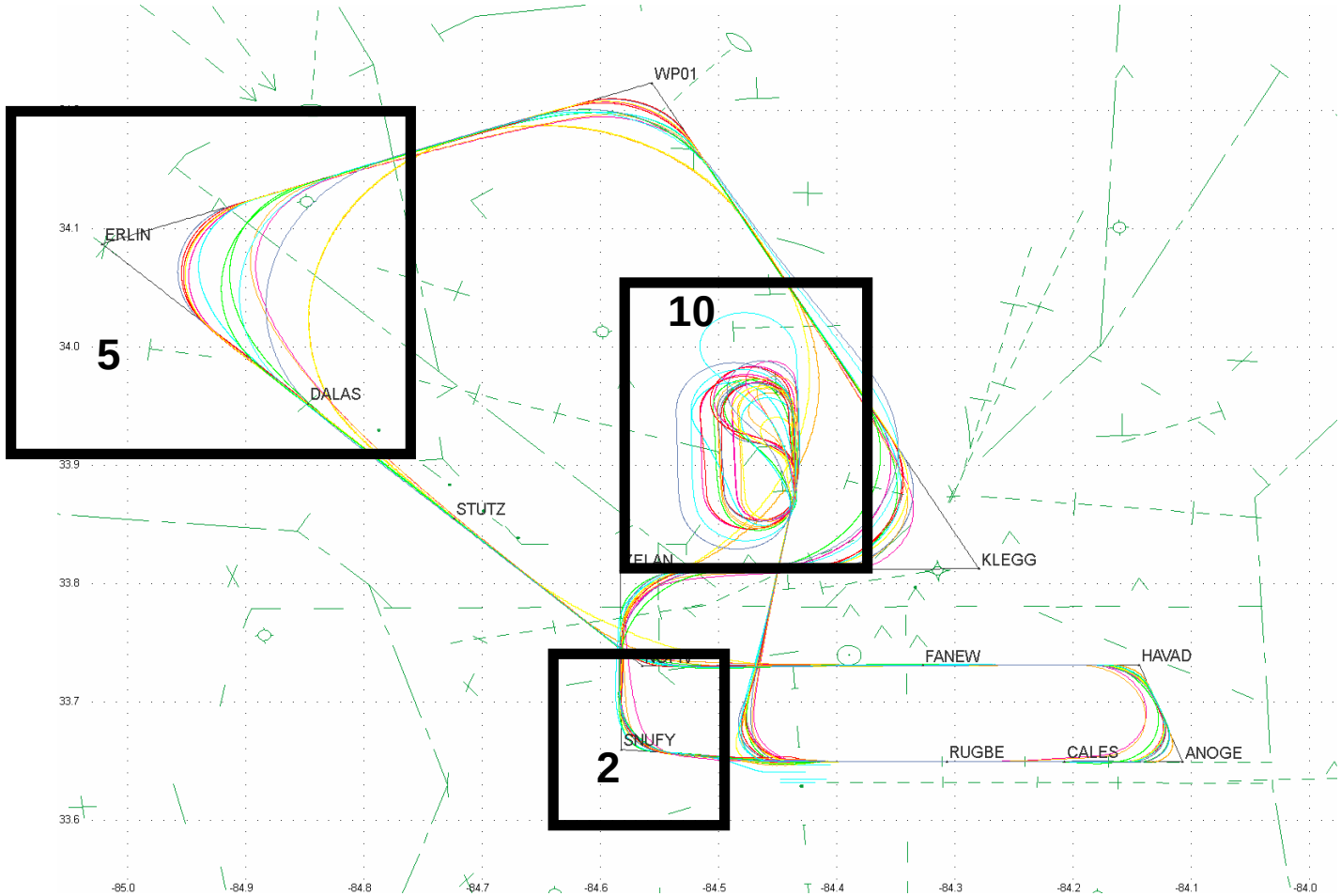


Summary of Track Data

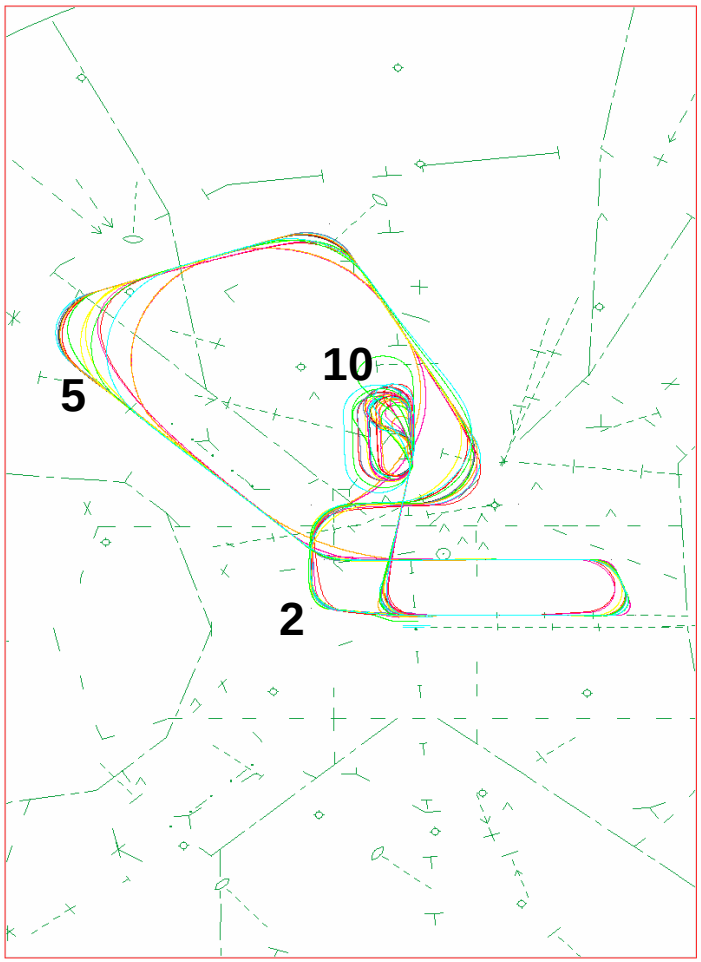
Summary of Tracks

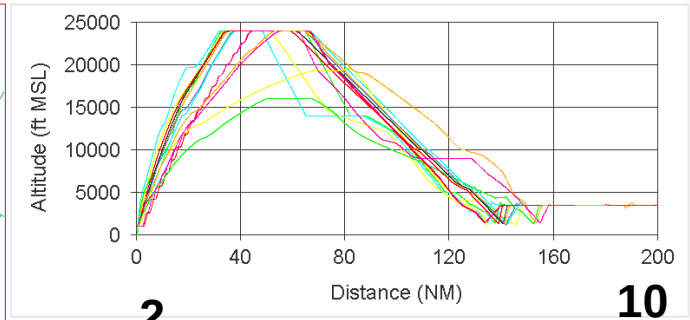


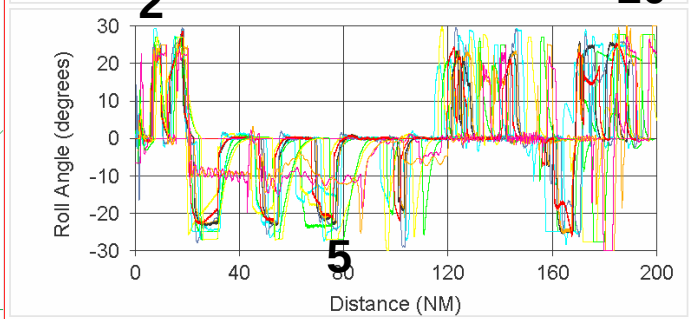
Summary of Tracks

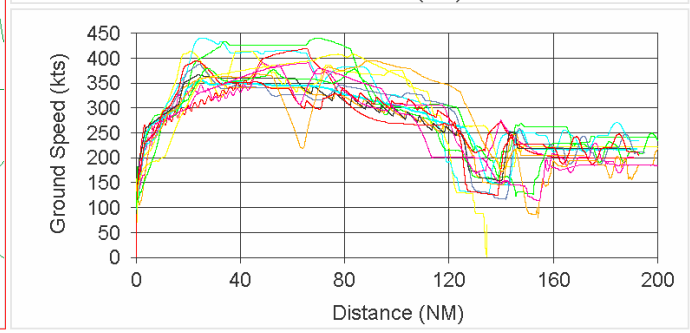


Summary of Tracks (altitude, roll angle, ground speed)



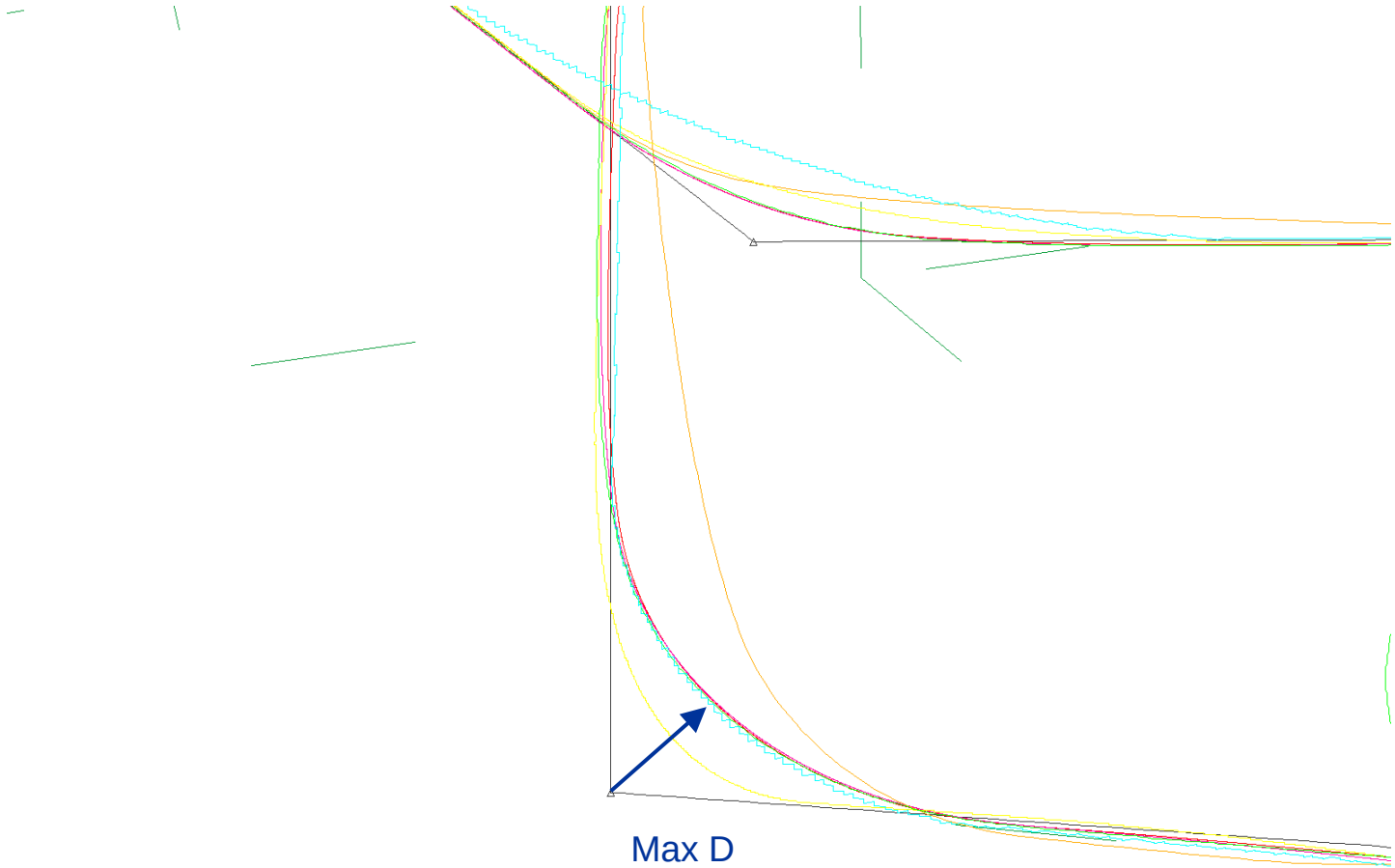




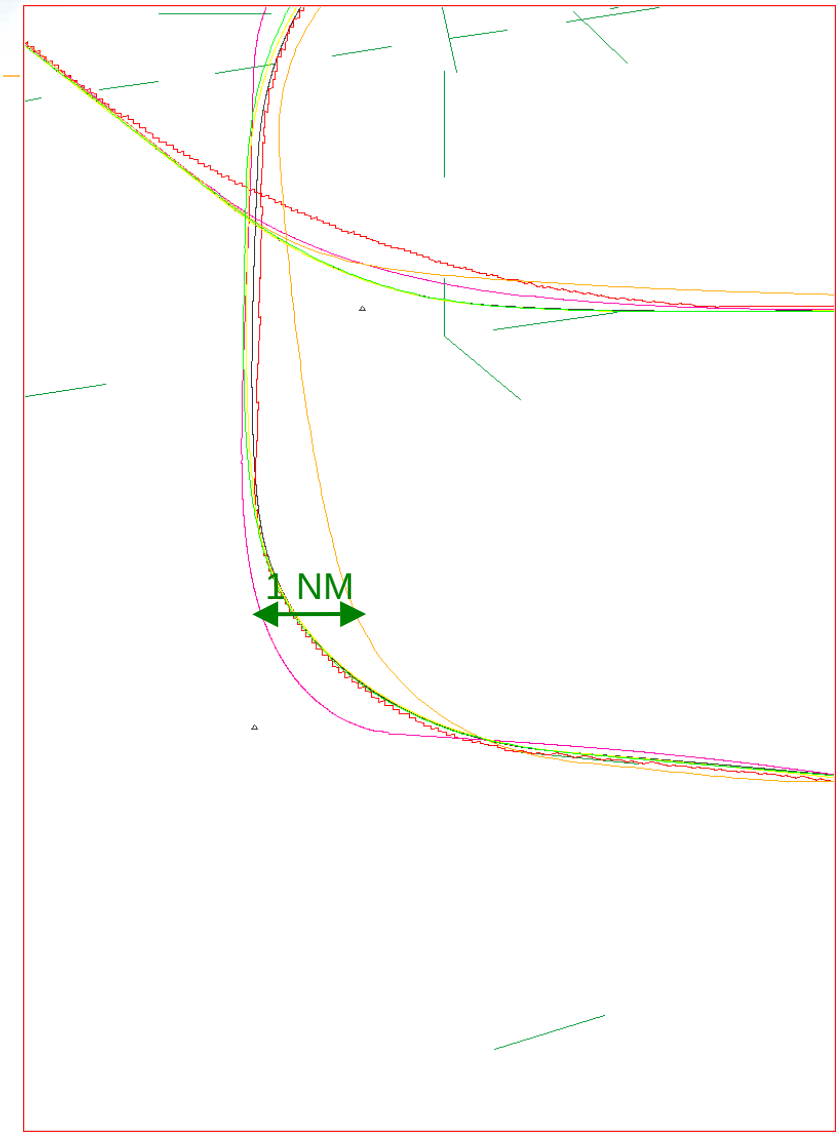


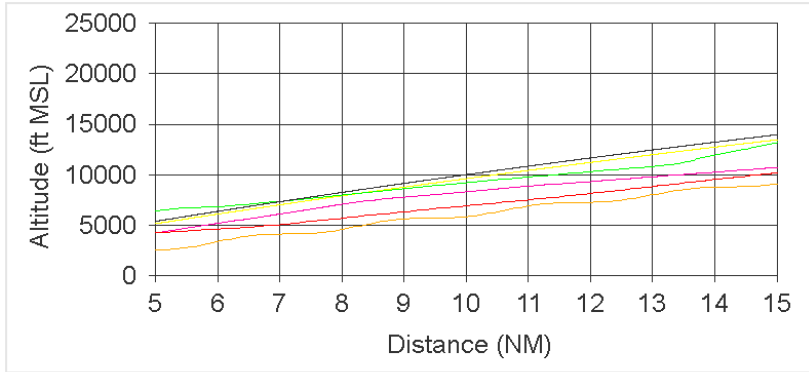
Summary of Track Data

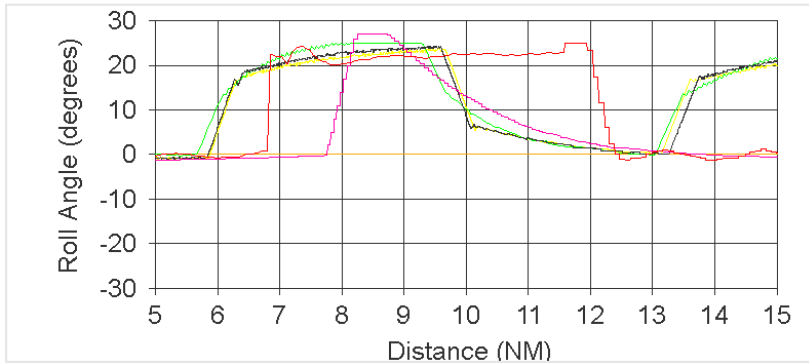
Turn # 2, No Wind

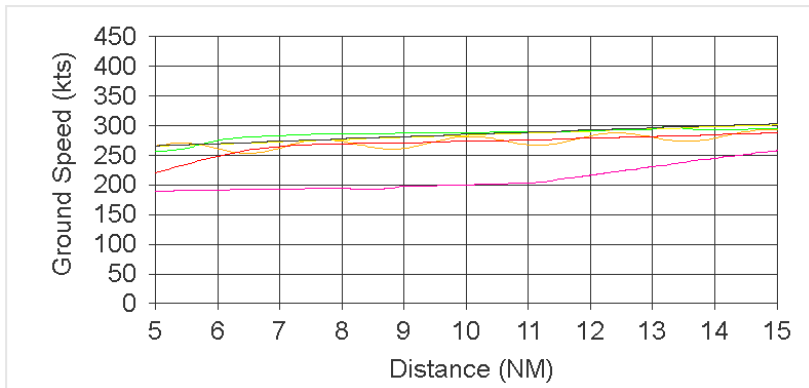


Turn # 2, No Wind

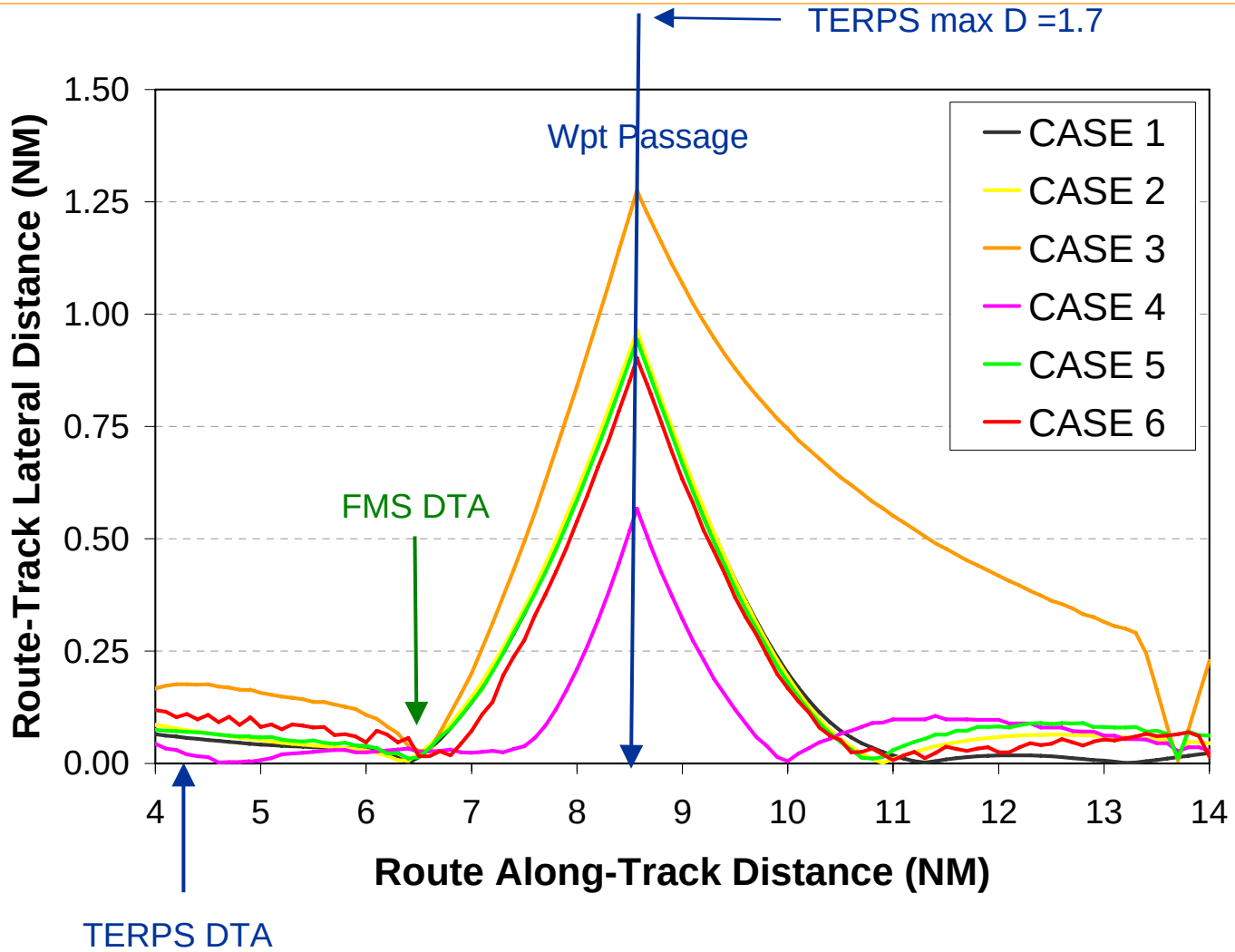








Turn # 2, No Wind



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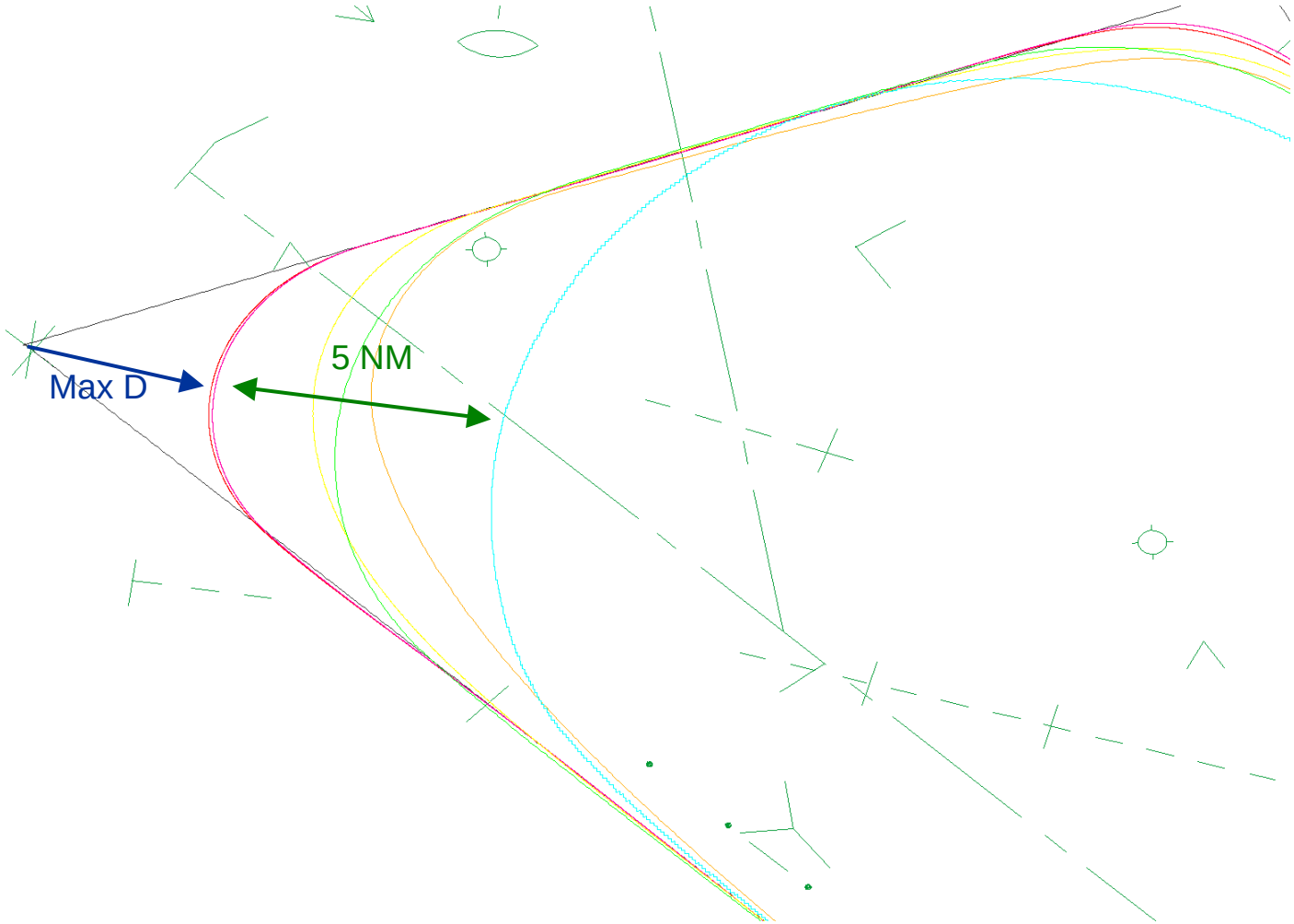
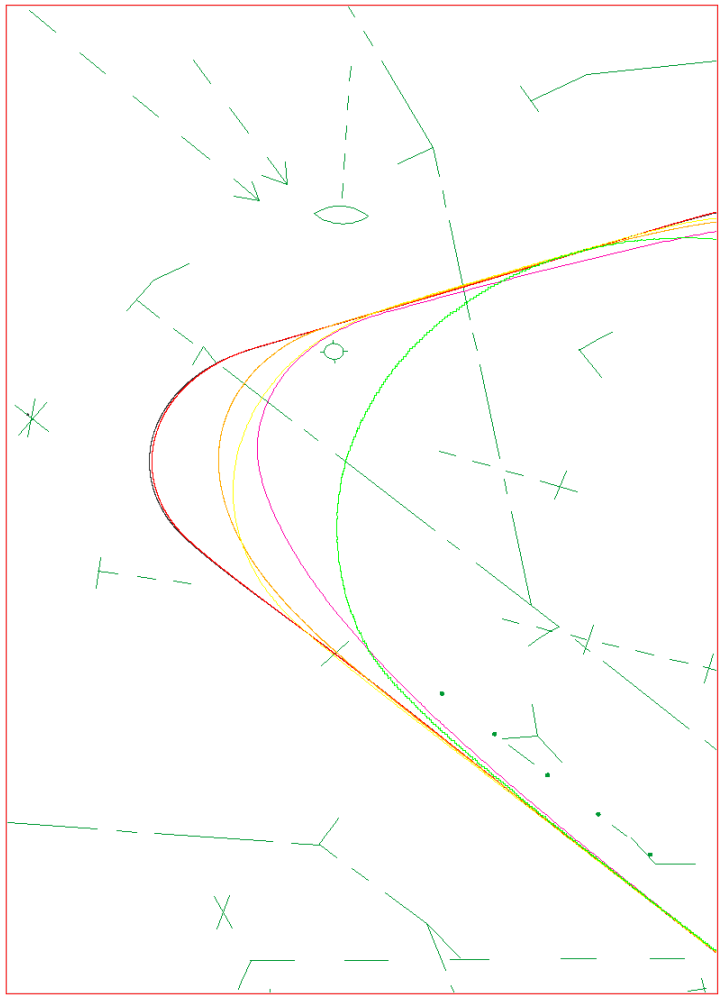
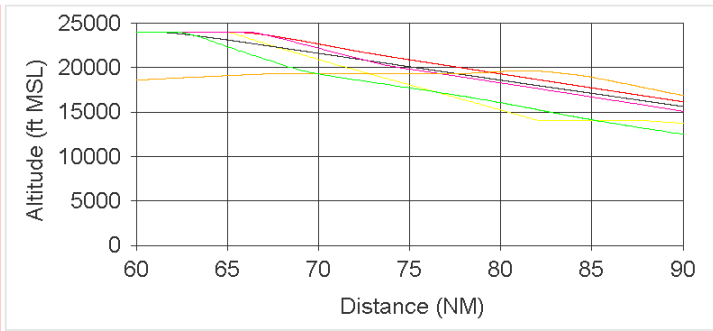
Arrival Descending Turn

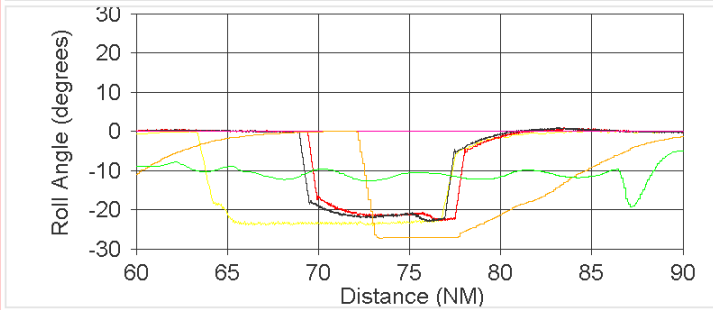
Turn # 5, No Wind

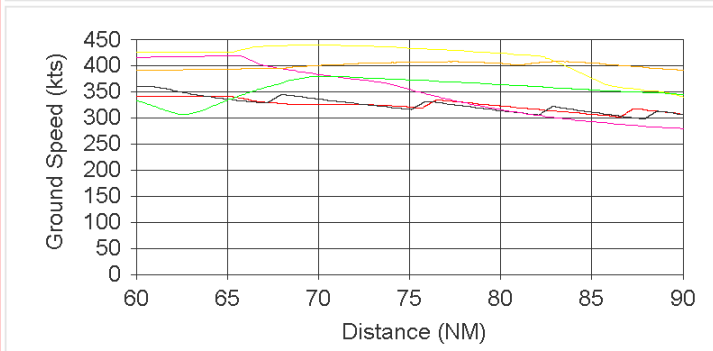


Turn # 5, No Wind

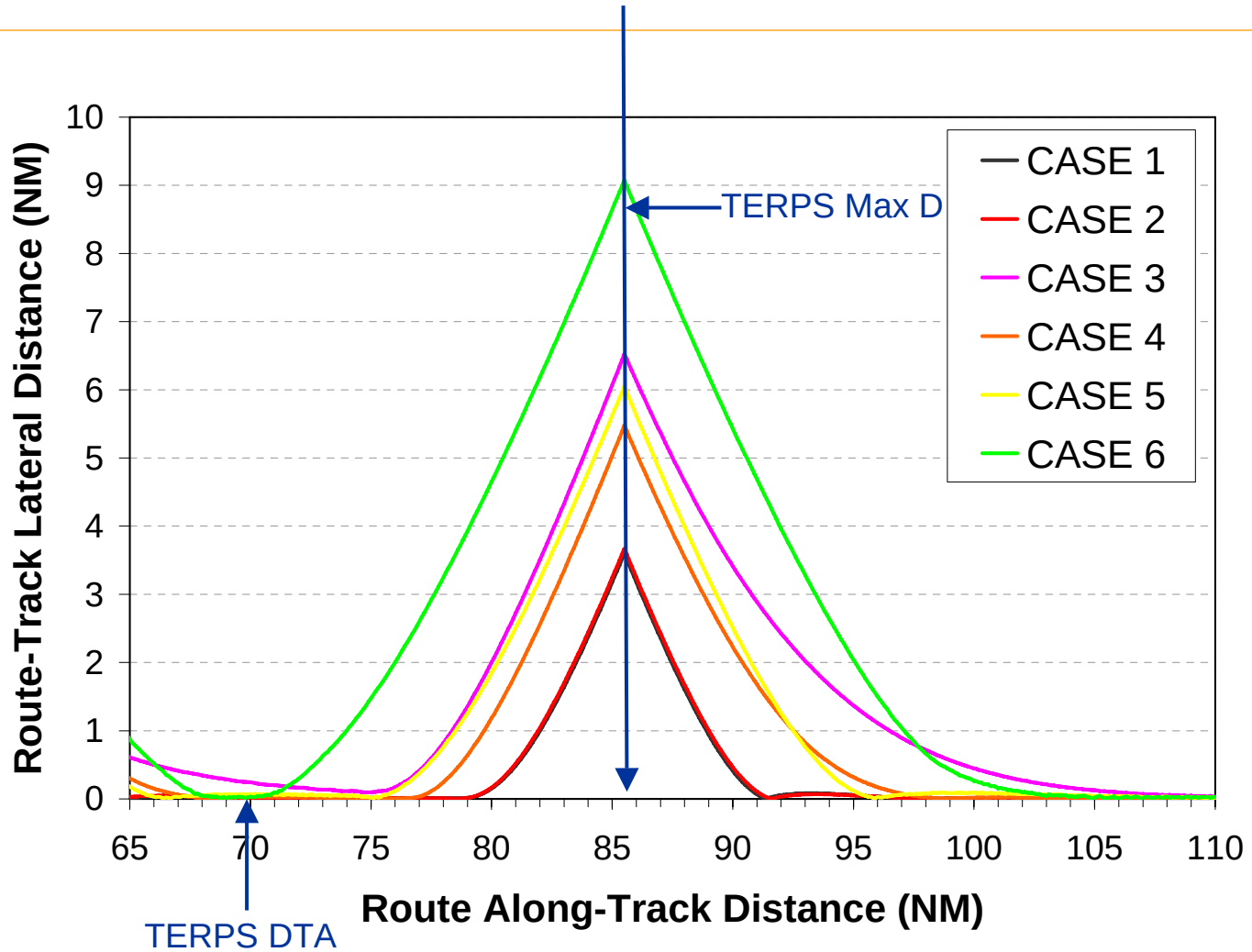






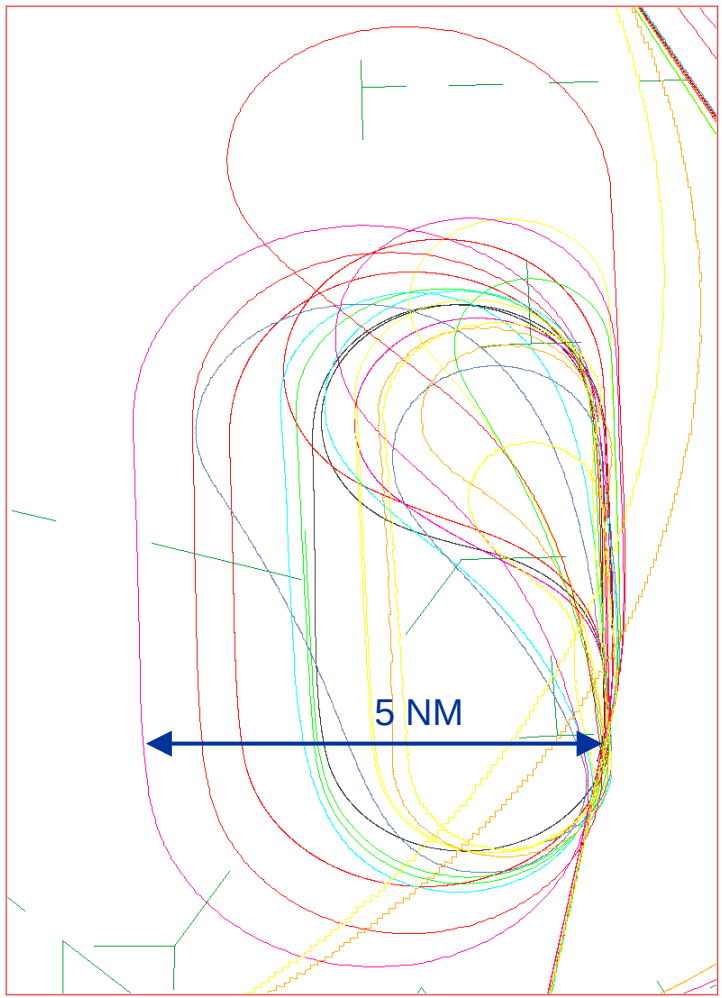


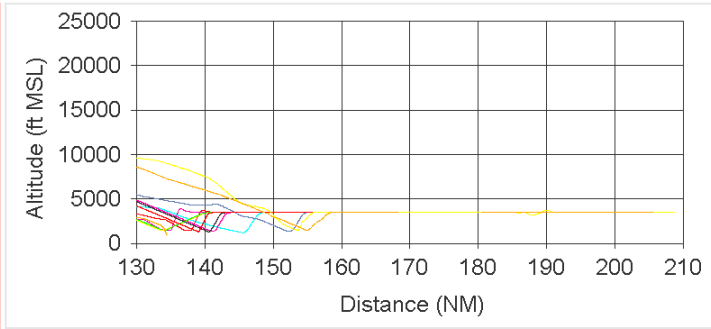
Turn # 5, No Wind

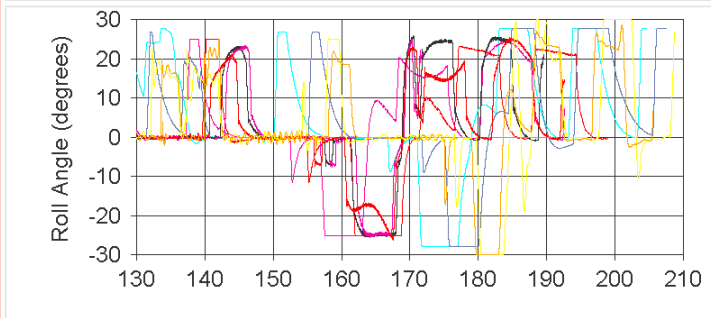


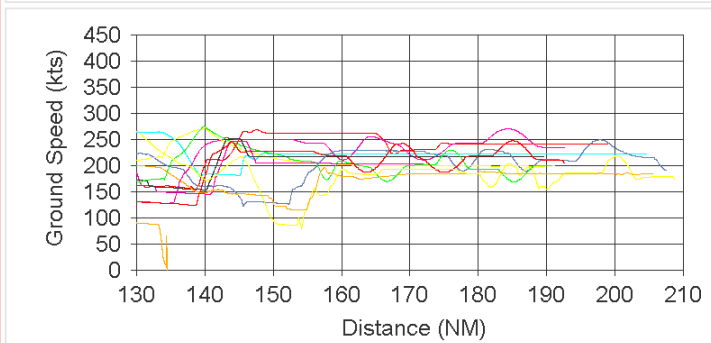
Standard Holding

Hold, All Tracks, No Wind

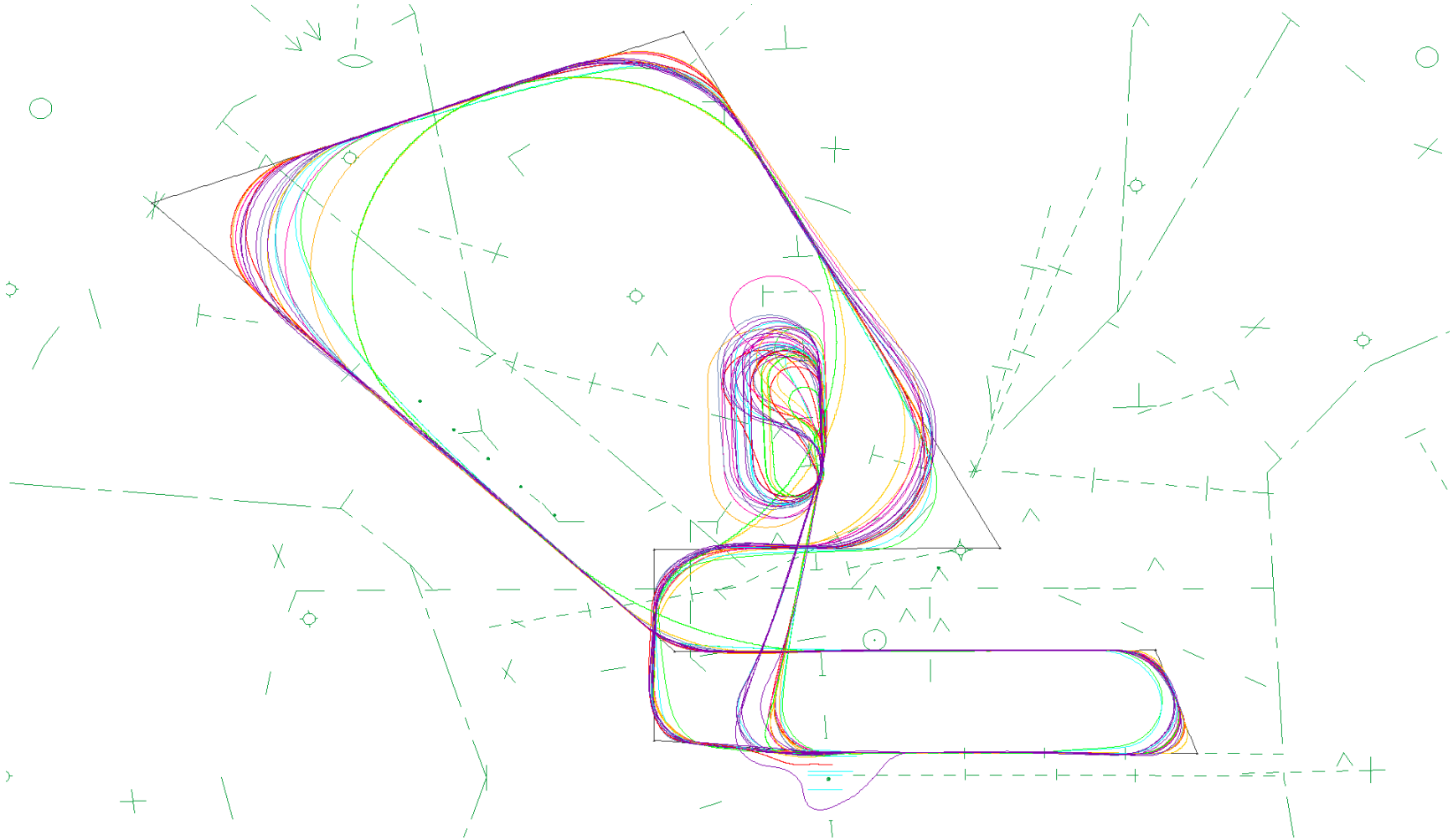


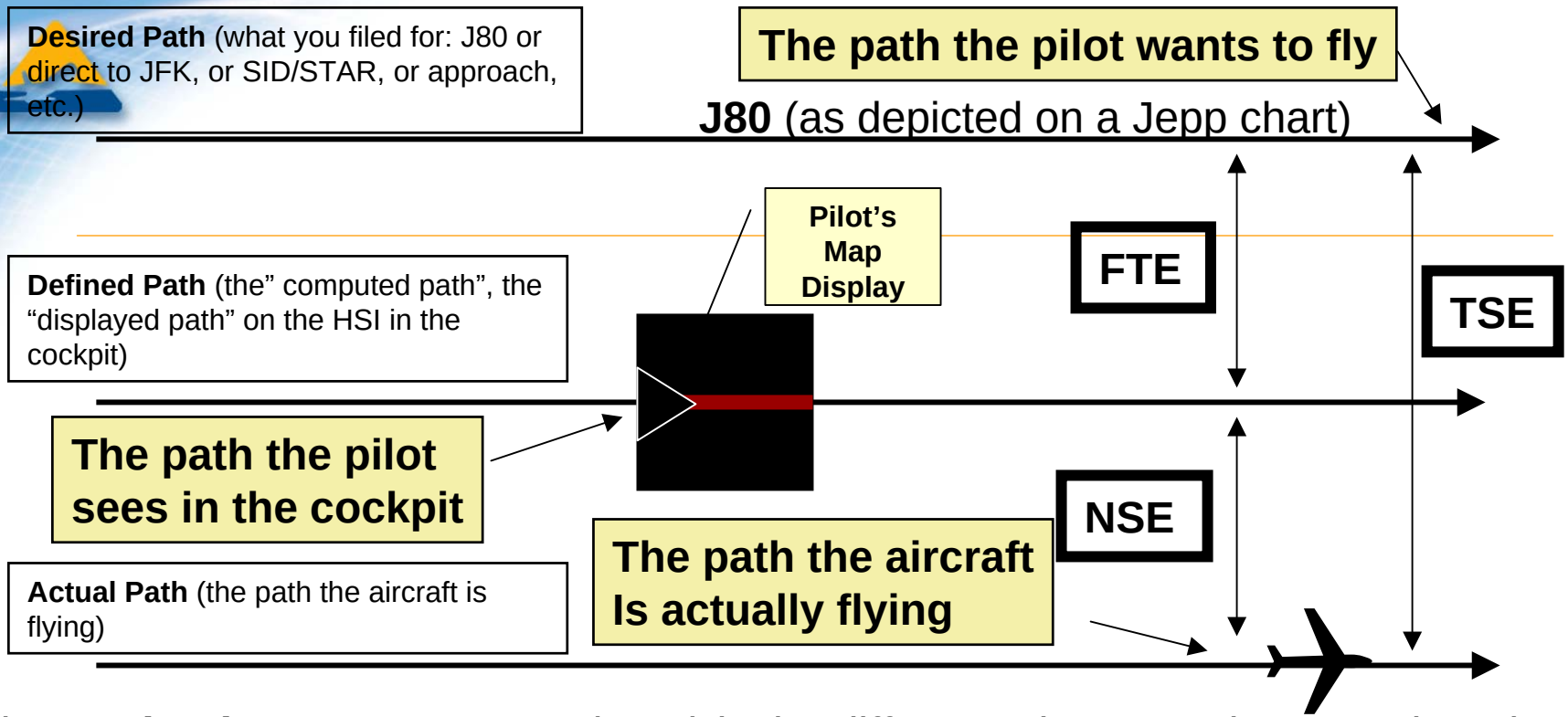






Summary of Tracks





The **Navigation System Error** (NSE) is the difference between the "actual" path of an aircraft and its "defined" (displayed or computed) path.
The difference between the "desired path" and the "defined path" is called **Flight Technical Error** (FTE). The vector sum of NSE and FTE is **Total System Error** (TSE).

From ICAO Doc. 9613/DO-208: **CROSS-TRACK ERROR** The perpendicular deviation that the airplane is to the left or right of the "desired path." This error is equal to the cross-track component of the Total System Error (TSE). *Note: Pilot sees Cross-Track on the CDU but not Cross-Track Error.*

See next slide for DO-236 definitions.

Recommendations

- Convene a panel of experts under the PARC to study these results and make recommendations to improve the standard set forth in DO-236B for lateral fly-by turn performance
- Extend the analysis to vertical path elements under the same venue as above
- Make much more standard use of RF and “fixed radius turns” to constrain turns in RNAV procedures (Near Term)
- Develop regulatory material to make FMC’s conform to holding pattern constructions of DO-236B Section 3.4.2.1
- Note – PARC has now set up a FMS Standards Action Team for these tasks.

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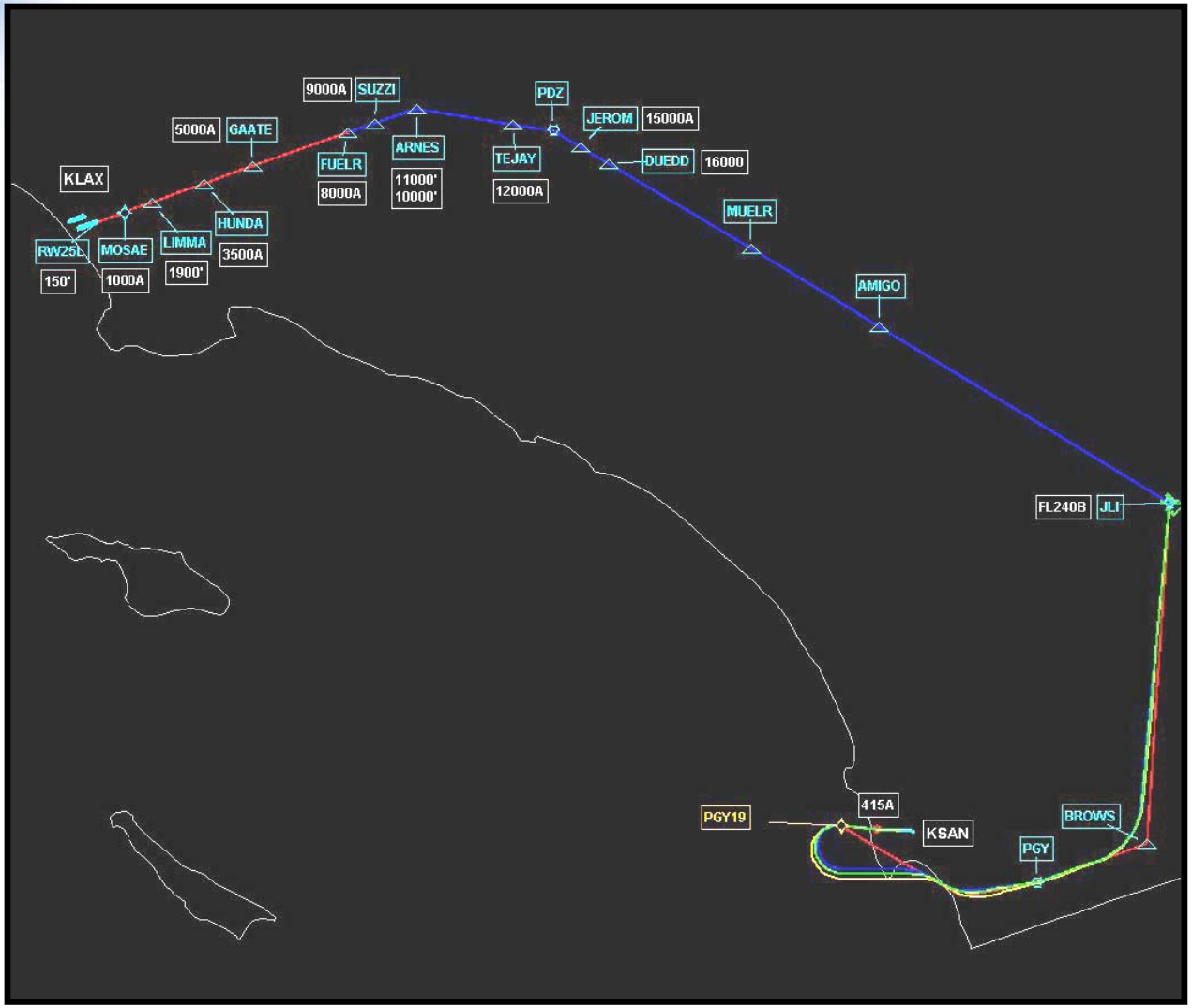
FMS Evaluation Test Plan



- **Route of Flight: KSAN-KLAX**
  - **Border Five Departure (RNAV)**
  - **Paradise Four Arrival (RNAV)**
  - **LAX Approach RNAV (GPS) RWY 25L**
- **No Wind**
- **Analyze *Aircraft* path**
  - **Not FMS calculated path**

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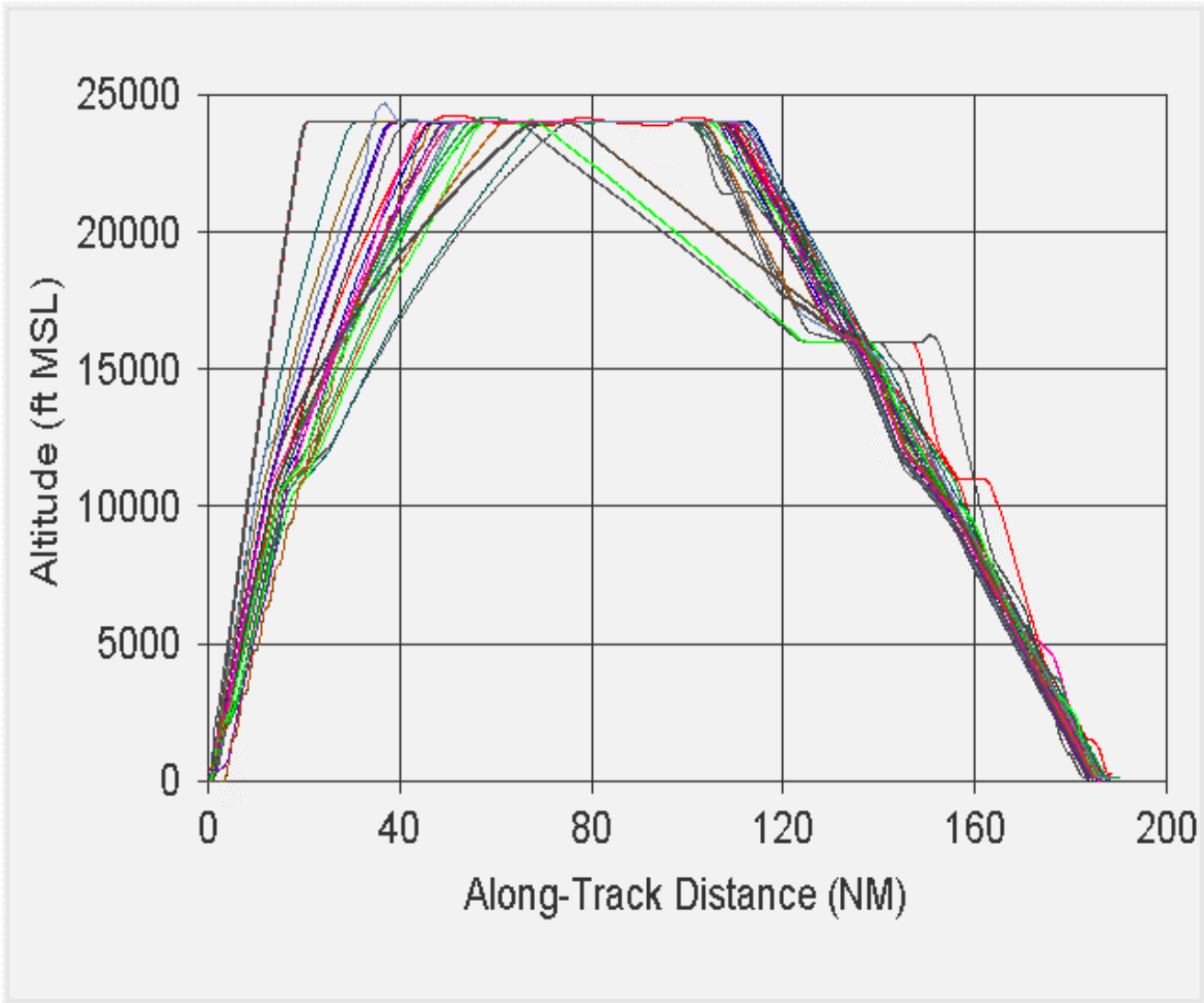
Manufacturers' & FMC's

Manufacturer	FMC	Aircraft
Smiths Aerospace	U10.5	FAA B737-800 Simulator
	U10.6	B737-600 MITRE Lab Test Bench
	U10.6	B737-600 sFMS USB Test Bench
Thales Smiths	FMS2	Airbus 320 Test Bench
Honeywell	Primus EPIC	Embraer 190 Test Bench
	Primus EPIC	Gulfstream V Test Bench
	Legacy 400K	UAL Airbus 320 Simulator
	Pegasus 2005	JBU Airbus 320 Simulator
	Pegasus 2005	B767-300 Test Bench

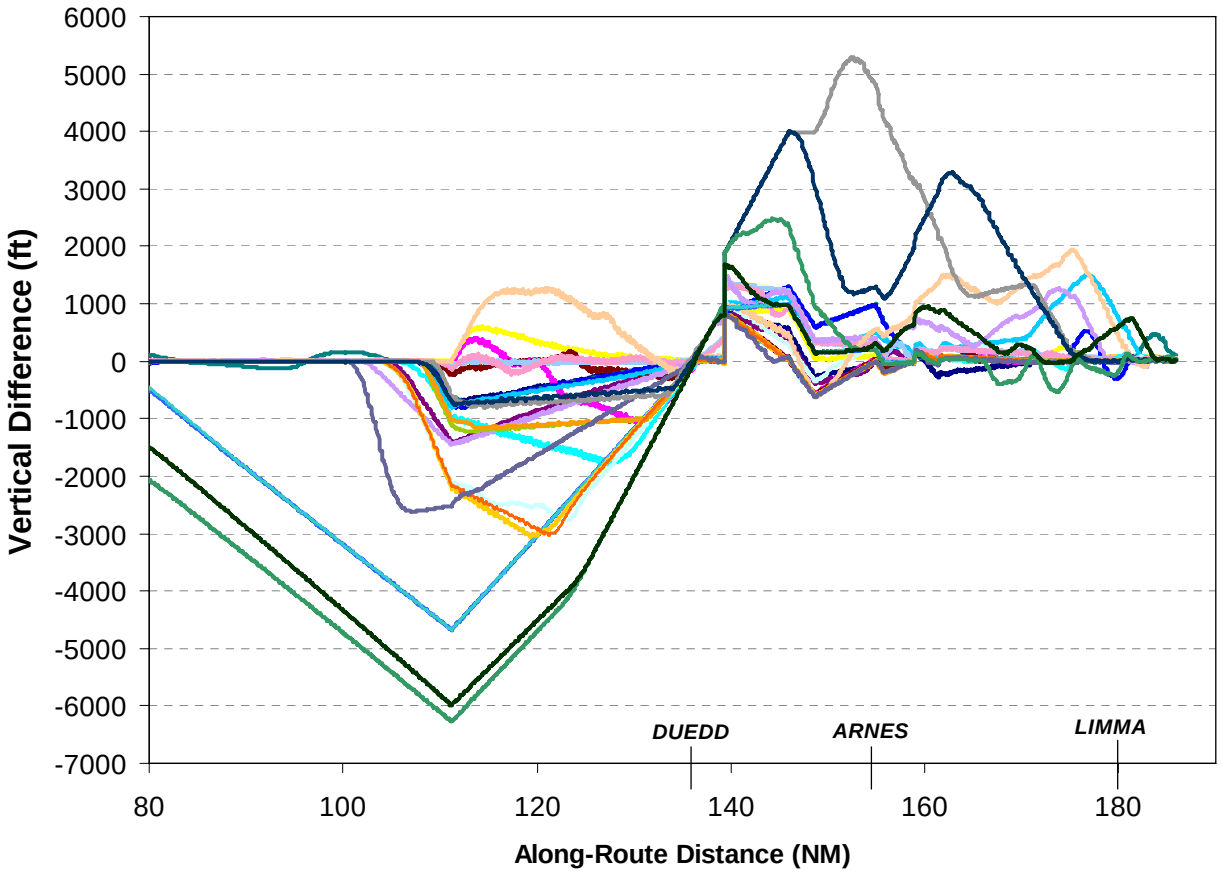
Manufacturers' & FMC's (continued)

Manufacturer	FMC	Aircraft
Honeywell	AIMS Block Point 2005	B777-200 Test Bench
	747-4 Load 16	B747-400 Test Bench
Rockwell Collins	FMS-4200	CRJ-700 Test Bench
Universal Avionics	UNS1-E	Cessna Citation II Test Bench
CMC Electronics	CMA-900	B747-200 Test Bench

All
Altitude Profiles



Vertical Route Conformance Observations
All Speeds

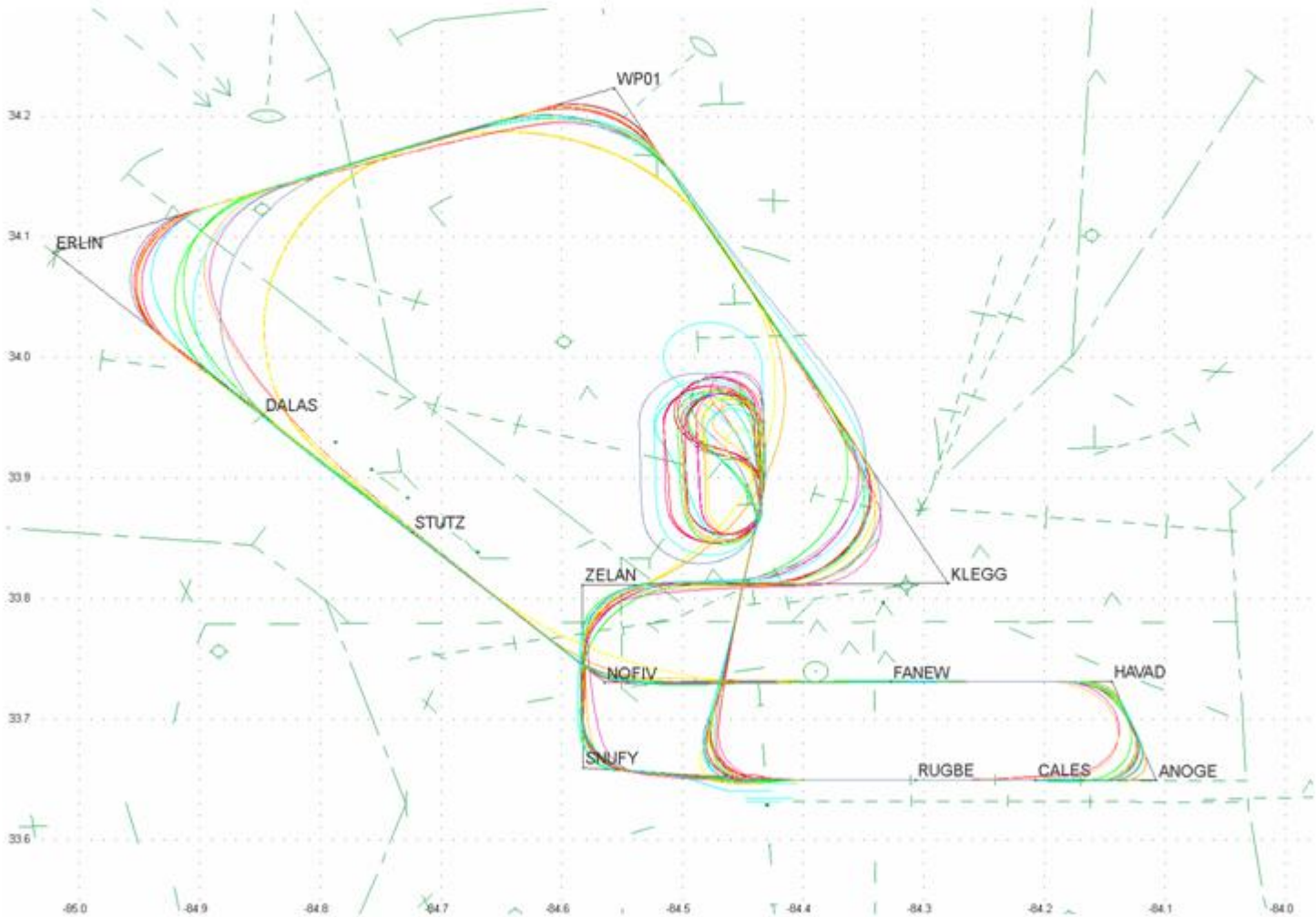


- **Significant variation <u>in between</u> waypoint constraints as well as <u>at</u> waypoint constraints**
- **Variations may be partially due to attempts to fly optimal path between constraints**
- **"Between" constraints not handled by some systems**

Public Link to:
MITRE 2006 Technical Papers

- http://www.mitre.org/work/tech_papers/tech_papers_06/index.html

Summary of Tracks



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RNAV/RNP CAPABILITY UPDATE

Aeronautical Charting Forum

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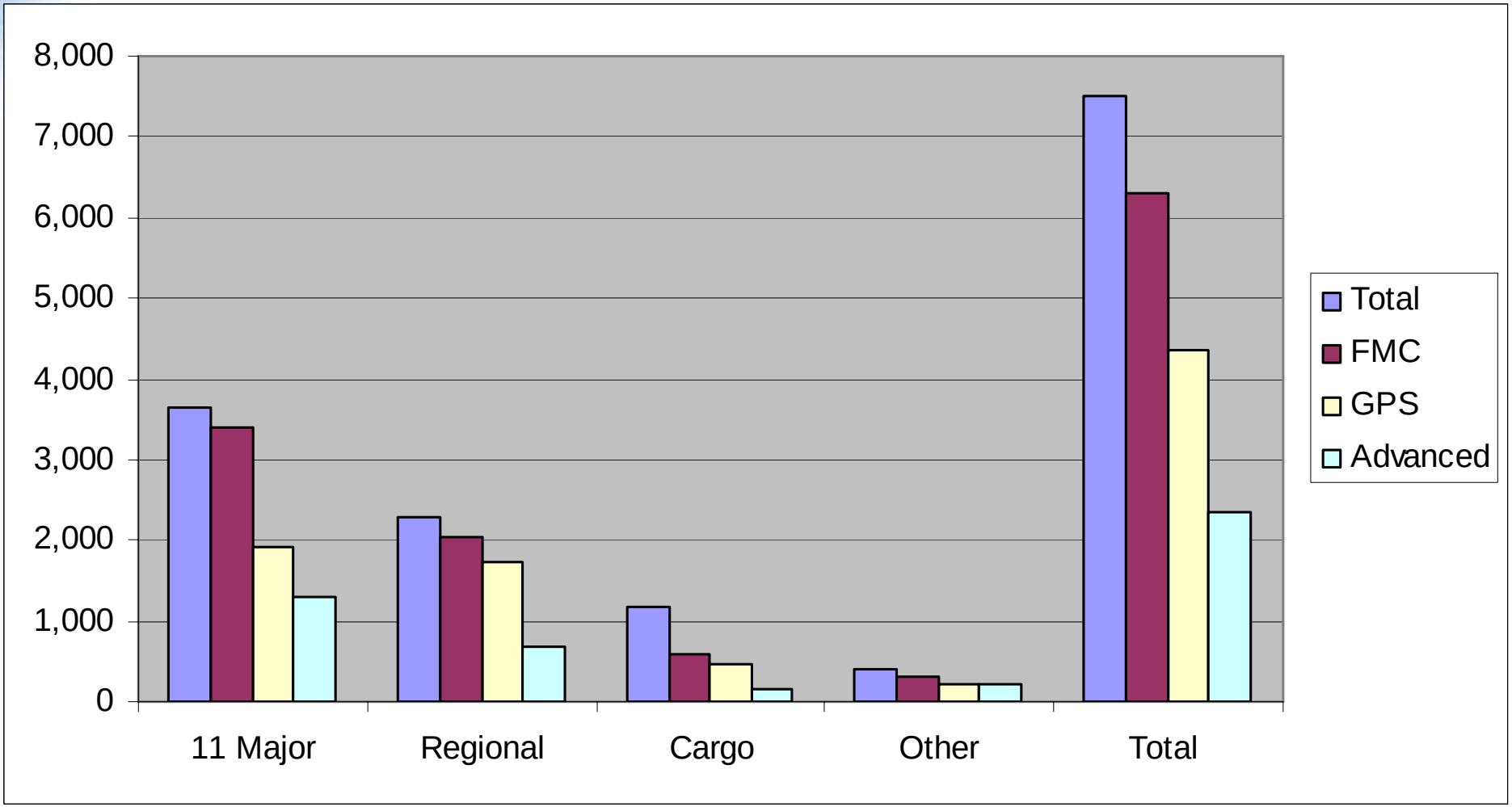
Part 121 Aircraft in the NAS
1st Quarter, 2007

	TOTAL	GPS	%	FMC	%	Advanced	%
11 PAX MAJOR	3,645	1,910	52%	3,405	93%	1,295	33%
REGIONAL	2,291	1,741	76%	2,027	88%	693	30%
CARGO	1,167	468	40%	582	50%	155	13%
OTHER	414	229	55%	298	72%	206	50%
TOTAL	7,517	4,348	59%	6,312	84%	2,349	31%

*Advanced = FMS's + IRU's + GPS's + RNP ALERTING + RF

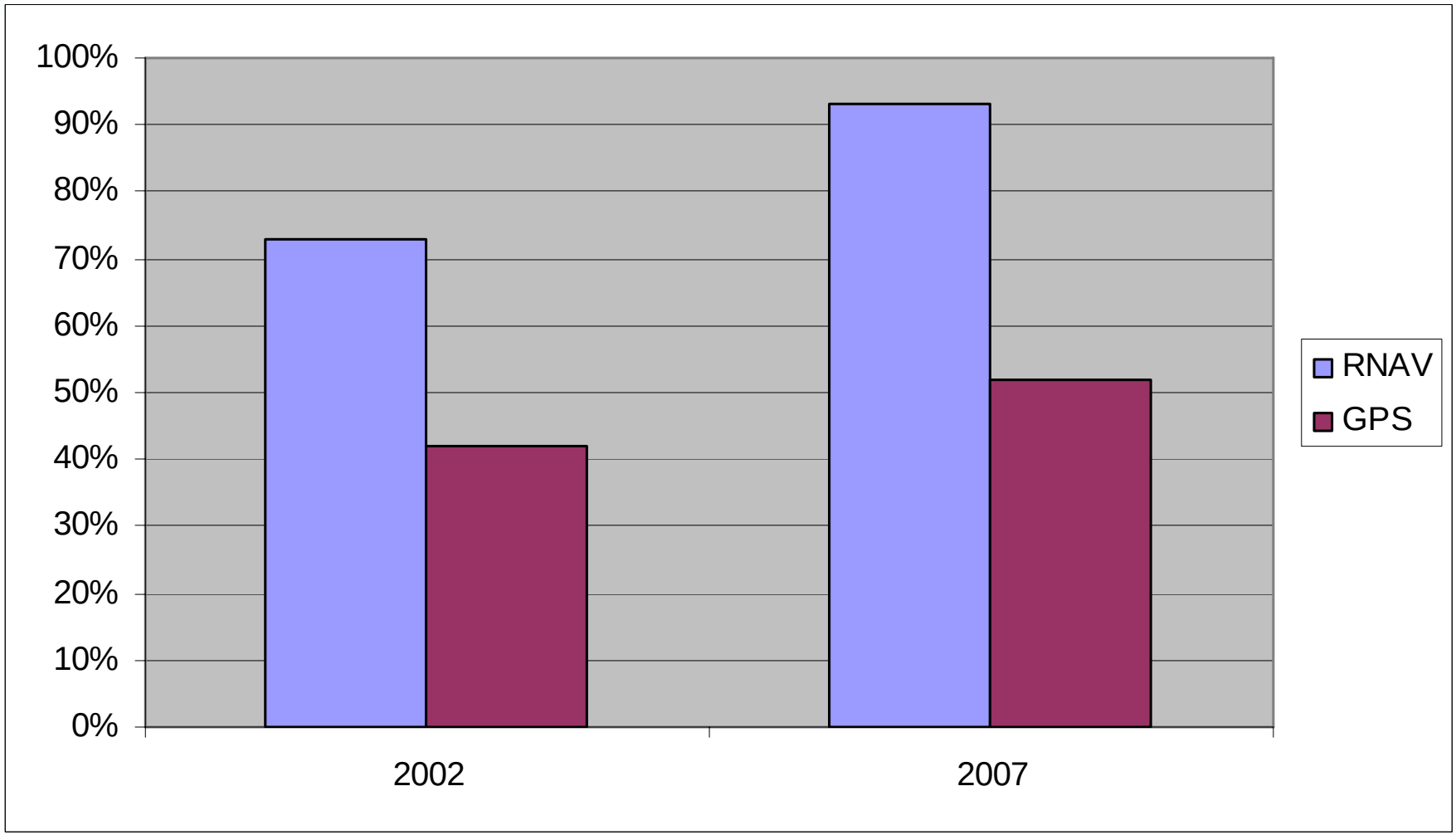
Part 121 Aircraft in the NAS
1st Quarter, 2007



Part 121 Jets/Props
1st Quarter, 2007

	TOTAL	JETS	%	TURBO PROP	%	RECIP	%
11 MAJOR	3,645	3,645	100%	0	0	0	0
REGIONAL	2,291	1,704	74%	587	26%	0	0
CARGO	1,167	1,084	93%	52	4%	31	3%
OTHER	414	392	95%	22	5%	0	0
TOTAL	7,517	6825	90.7%	661	9%	31	.3%

RNAV & GPS Increases
Part 121 Major Airlines
(11 PAX & 2 Cargo)



To Date
04/25/2007
Airlines that have a username and password and/or have completed or partially completed the "equipment section" of the web based Operator Survey

ABX	ATA	Flight Options	NetJets Int'l	Spirit
Air Canada Jazz	Air Transport Int'l	Frontier	NetJets Large	Trans States
Air Wisconsin	Atlantic SE	GoJet	North American	United*
Air Tran	Atlas	Horizon*	Northwest*	UPS
Aloha	Chautauqua	JetBlue	Pace Aviation	US Airways*
America West*	Continental*	Kalitta Air	Pinnacle	World
American*	Comair	Mesa	PSA	
American Eagle*	Delta*	Mesaba	Ryan Air	
Allegiant	Executive Jet Mgt	Miami Air	SkyWest	
Alaska*	Express Jet*	Midwest	Southern Air	
Astar Air Cargo	FedEx	NetJets	Southwest*	

*Completed the original paper survey.