Modeling ATM Interruptions

Tara Weidner & Goli Davidson
Seagull Technology, Inc.

Rich Coppenbarger & Steve Green
NASA Ames Research Center

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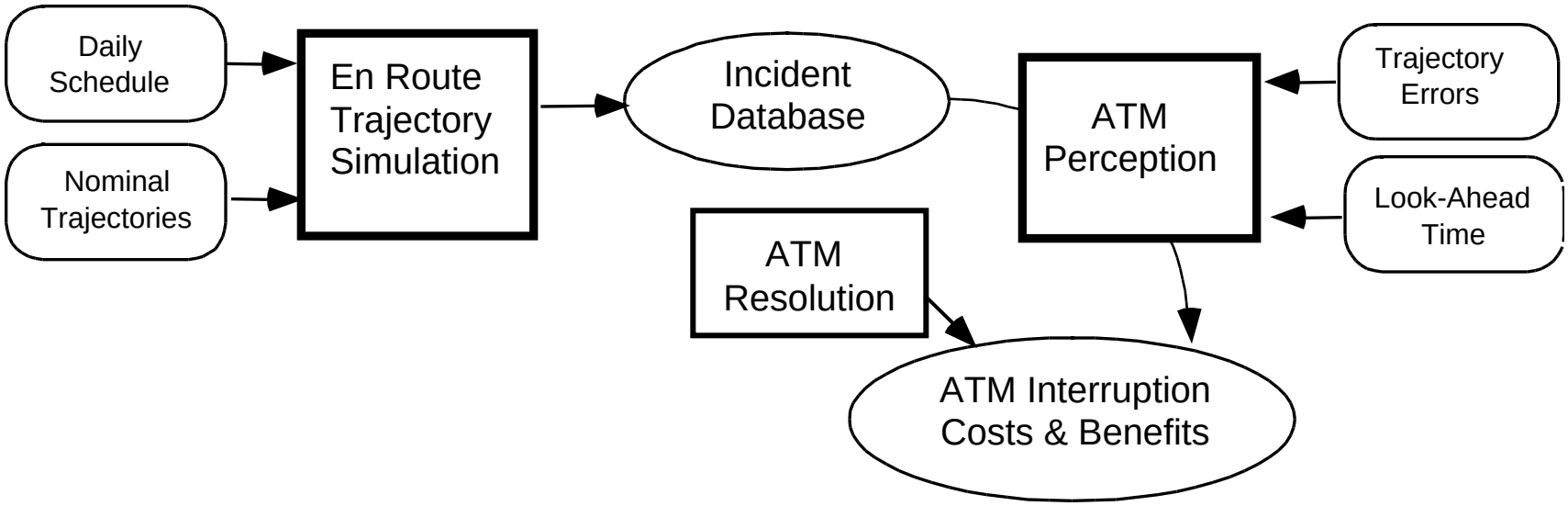
ATM Interruptions Methodology

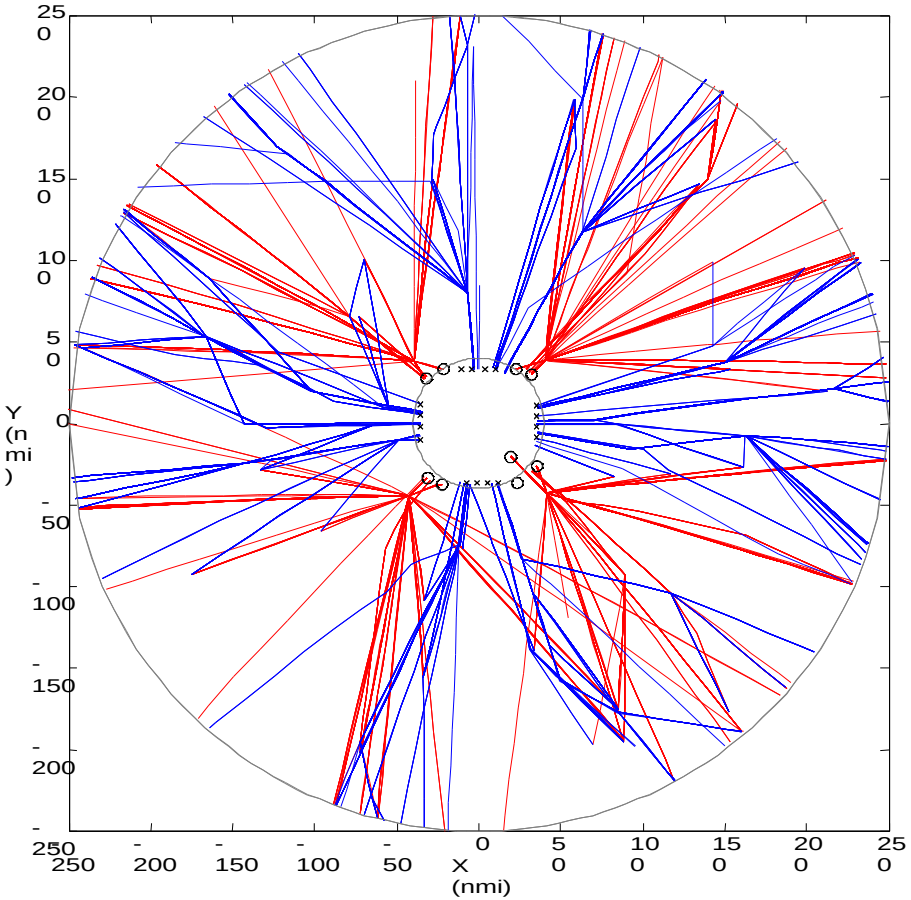


Outline:

- **Overview ATM Interruptions Model**
- **Illustrative Example**
- **Conclusions**

Nominal Trajectories: Arrivals/ Departures

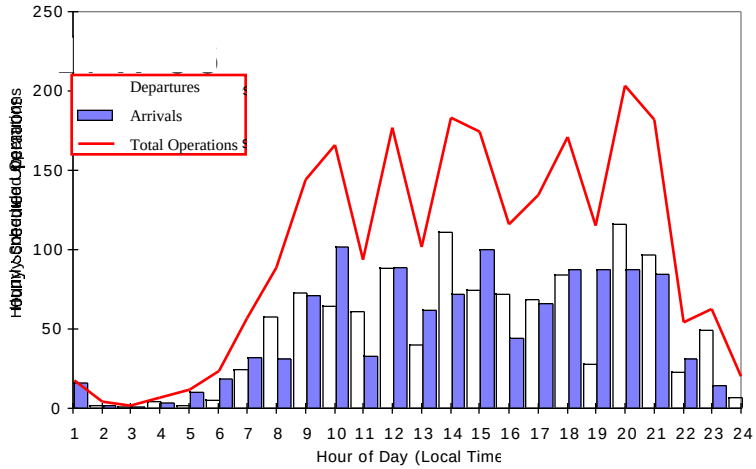
Analyzed all operations within 40-250 nm from DFW, above FL100



Arrivals

Departures

ETMS flight plans from Friday, June 14, 1996



Satellite Airport/Overflight Trajectories

Profile View (S-N)

	DFW Satellite Airport	Daily Ops
IAH	Houston Apt	1,043
HOU	William Hobby Apt	497
DAL	Dallas Love Field Apt	468
SAT	San Antonio Intl Apt	432
AUS	Robert Mueller Muni Apt	377
OKC	Will Rogers World Apt	276
TUL	Tulsa Intl Apt	261
SPS	Wichita Falls Muni Apt	156
SHV	Shreveport Regional Apt	136
LBB	Lubbock Intl Apt	128
	Top 10 DFW Satellite	3,774 (83%)
	DFW Satellite Ops	4,005
	DFW Overflight Ops	527

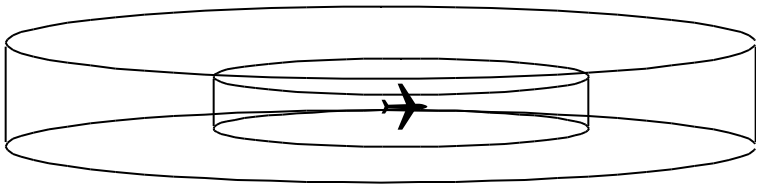
Plan View

Incident Database

Objective:

Create database of all conflicts/near-conflicts from DFW Airspace Model trajectories (x,y,z,t)

- Filter to identify unique 2-aircraft incidents
  (less than 12 nm horizontally & 1400'/2400' vertically)



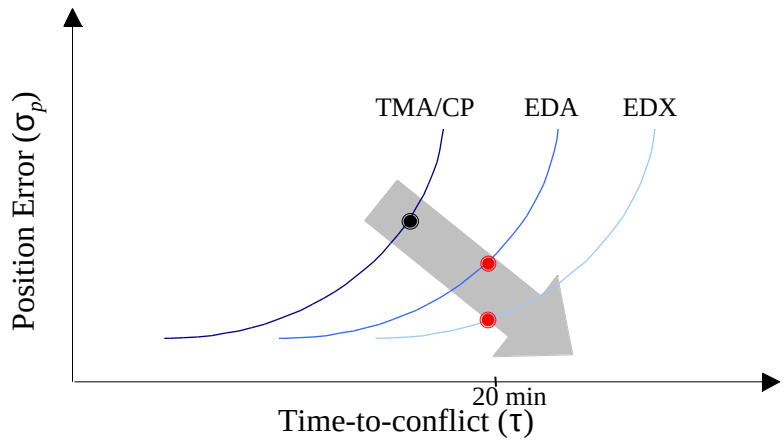
Min Sep. Requirement + Buffer

- Calculate incident attributes
  - Miss distance (horiz/vert distance, time, location)
  - Operations Type (arrival, departure, overflight)
  - Flight mode (climb, descent, cruise)
  - Other as needed to categorize incident or ATM perception accuracy (arr/dep fix, relative speeds and headings)

ATM Perception

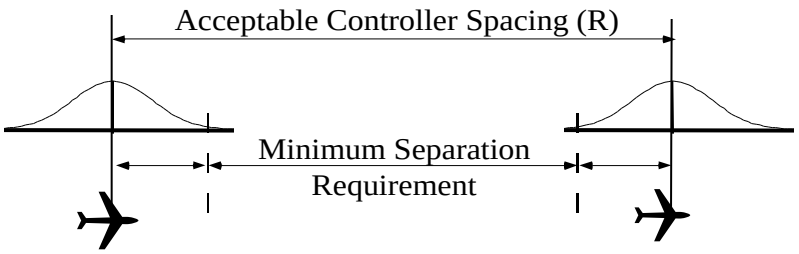
Tool Accuracy...

$\sigma_{position}$ & σ_{speed}



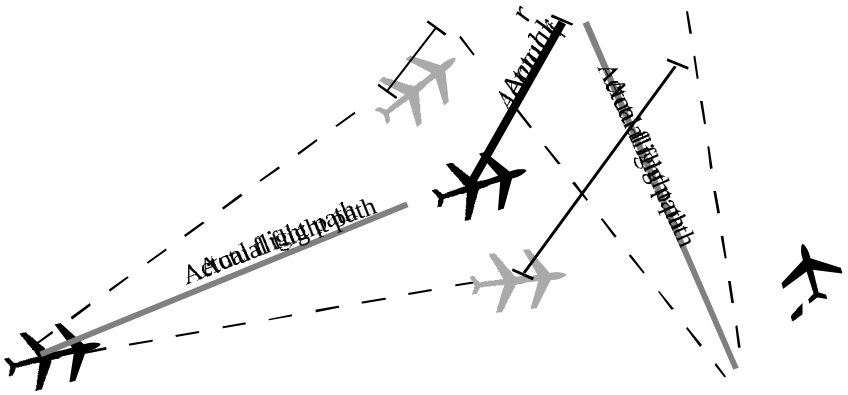
Acceptable Controller Spacing (R)

$$R = n\sigma_p + \textit{Min Sep Reqmn't}$$



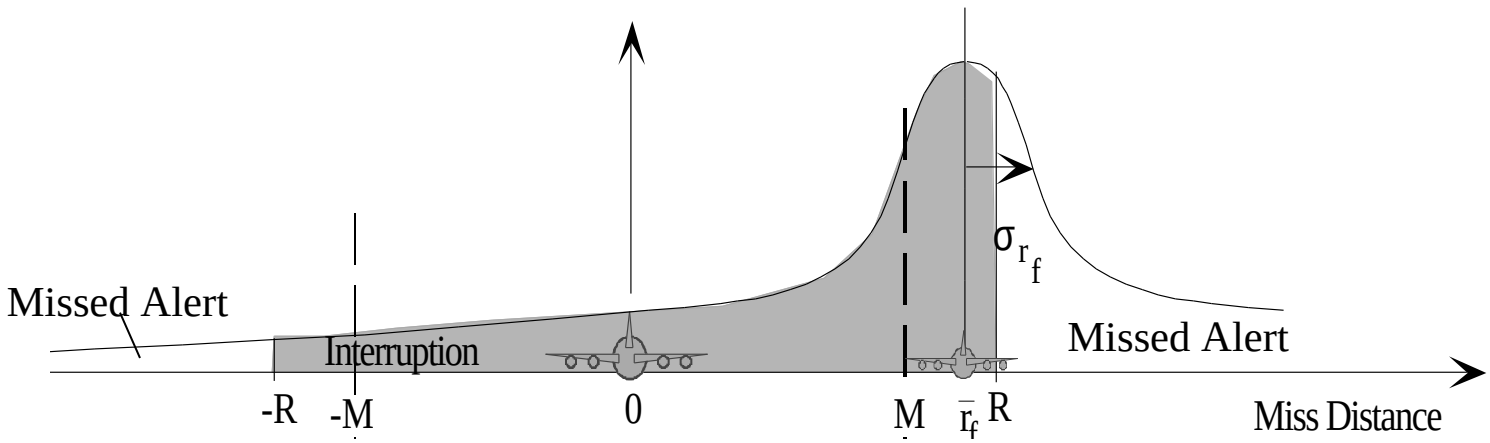
Perceived Miss Distance ~N(r_f, σ_{rf})

$$\sigma_{r_f} = \sqrt{2\sigma_p^2 + 2\sigma_v^2\tau^2}$$



Perceived ATM Interruptions (1 of 2)

- **For Each Incident…**



- **Incident, Miss Distance (r_f)**
- **Perception**
  - Distribution of Perceived Miss Distance ~N(r_f, σ_{rf})
  - Acceptable Controller Spacing (± R)
    (Min Sep Reqmn't, ± M + buffer)
- **Intervene when Perceive Miss Distance < ±R**
  (shaded area)

$$P(conflict) = \frac{1}{2} erf\left(\frac{R + r_f}{\sqrt{2}\sigma_{r_f}}\right) + \frac{1}{2} erf\left(\frac{R - r_f}{\sqrt{2}\sigma_{r_f}}\right)$$

Perceived ATM Interruptions (2 of 2)

For each incident, at a given tool accuracy...

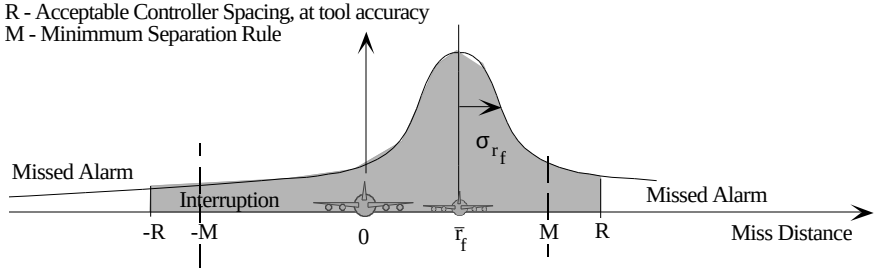
Compare
Incident Minimum Distance ($\bar{r}_f$)
with Perception (σ_{r_f},R)

Probability of Interruption

Resolution Cost

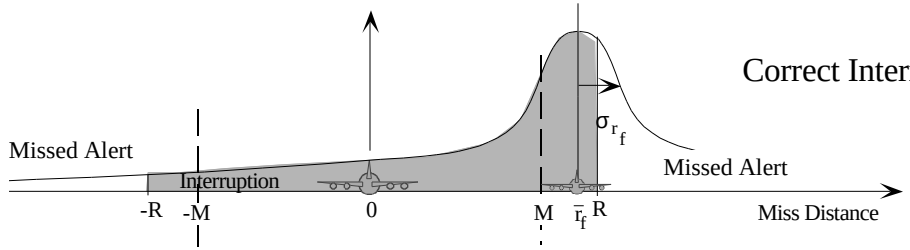
Violate Minimums

R - Acceptable Controller Spacing, at tool accuracy
M - Minimmum Separation Rule



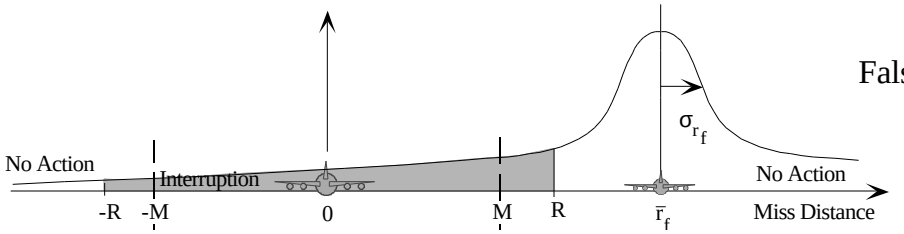
Correct Interruption	▒	$ C, strategic
Missed Alarm	□	$ C^+, tactical
	100%	

Violate Acceptable Controller Spacing



Correct Interruption at tool accuracy	▒	$ C, strategic
Missed Alarm	□	$$C^+$, tactical
	100%	

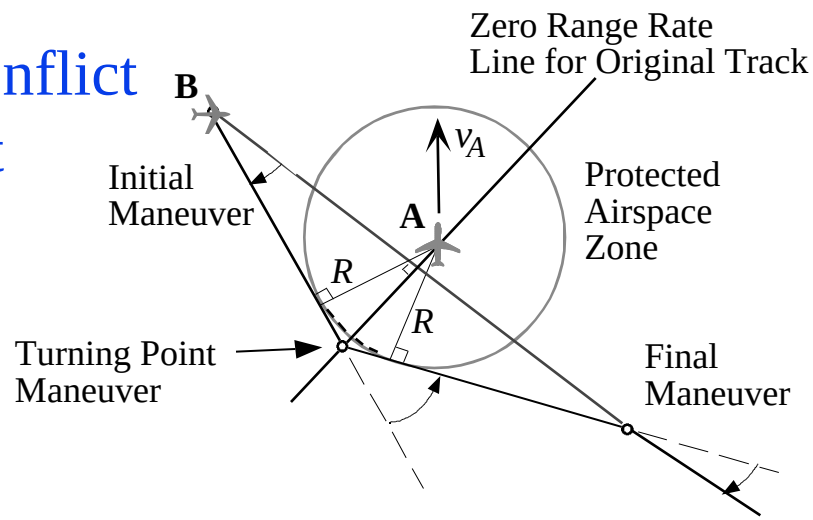
False Alerts



False Alert Interruption	▒	$ C^-, strategic
No Action	□	$ 0
	100%	

Resolution Costs

- **Resolution Maneuver**
  - Vectoring resolutions ONLY (backside/frontside depending on geometry)
  - Maneuvering shared by both aircraft
  - Trajectories not altered
  - Strategic, 10-20 min time-to conflict
  - Tactical, 5 min time-to-conflict



- **Resolution Cost**
  - Fuel Cost ONLY

$$TC = (\Delta S / V_{initial}) \times \begin{matrix} Fuelburn \\ Rate \end{matrix} \times C_{fuel}$$

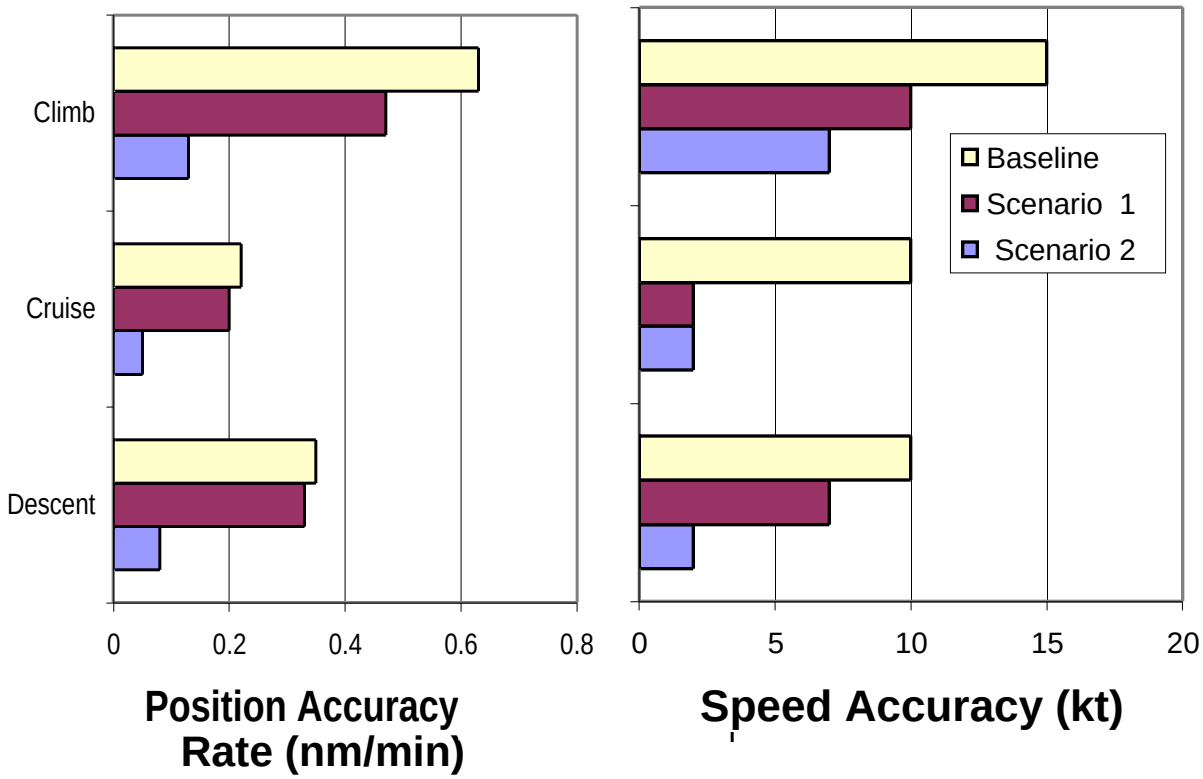
- **Special Cases**
  - Arr-Arr, Dep-Dep, $1/resolution
  - False Alerts, 1/3 strategic resolution costs
  - Others (average costs of relevant category)

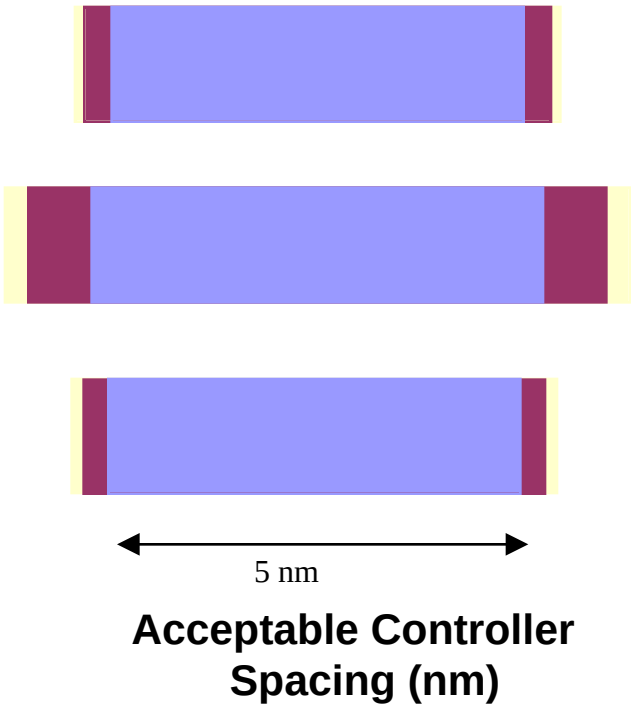
Illustrative Example

Improved Conflict Probe trajectory prediction accuracy and leads to reduced ATM interruptions

- **CTAS Baseline**
  - Conflict Probe (detection & resolution)
  - TMA sequencing & scheduling with DA advisories,
  - EDA-enabled arrival/departure Direct Routes
  - Manual flight control (no FMS)
- **Scenario 1 - FMS Flight Control**
- **Scenario 2 - FMS En Route Data Exchange**
  - FMS Flight Control
  - Calibration Data Exchange- aircraft weight, weather
  - User Preference Data Exchange - climb/descent speeds

Scenario Perception Parameters





Vertical Acceptable Controller Spacing (all Scenarios): 1400'/2400' above/below FL290
Strategic Lookahead Time (all Scenarios): 19 minutes before conflict start

CTAS Trajectory Variation and Prediction Accuracy

- **See FFP1 VG**

CTAS and Airline Aircraft Weight Accuracy

- **Use Airline data to improve EDX parameter estimates**

(data received too late to use in ATM Interruptions Analysis)

Aircraft Type	No.	TO Wt Mean Error (%) AOC	TO Wt Mean Error (%) CTAS	TOD Wt Mean Error (%) AOC	TOD Wt Mean Error (%) CTAS
MD-80	3,944	-0.1%	2.4%	0.5%	-4.7%
F-100	1,059	-0.2%	-11.0%	0.5%	-12.5%
B-757	629	0.2%	7.9%	0.6%	1.1%
B-727	560	-0.4%	-2.8%	0.5%	-0.5%
B-767	91	0.4%	13.2%	-0.1%	29.6%
MD-10	81	0.0%	-15.8%	0.1%	-5.9%
Wtd Ave	NA	0.1%	5.1%	0.5%	5.5%

Standard Deviation

Error Model Parameter	Units	Baseline Climb	Baseline Cruise	Baseline Dscnt	FMS Climb	FMS Cruise	FMS Dscnt	+Data Exchange Climb	+Data Exchange Cruise	+Data Exchange Dscnt
Initial Weight	%	10	10	**10**	10	10	10	2.5	10	**2.5**
Aerodynamic Drag	%	7	7	**7**	7	7	7	7	7	7
TOC/TOD Placement	nm	16	NA	**3**	7	NA	**0.5**	7	NA	0.5
Spd Adherence (IAS)	kt	15	10	**10**	10	2	**7**	**7**	2	2
X-Track Wander	nm	3	3	**3**	0.25	0.25	**0.25**	0.25	0.25	0.25
Aircraft Nav. Bias	deg.	2	2	**2**	2	2	2	2	2	2
Turn Dynamics	sec	5	5	**5**	1	1	**1**	1	1	1
Wind Forecast	kt	20	20	**20**	20	20	20	4	4	**4**
Temp. Forecast	°C	10	10	**10**	10	10	10	1	1	**1**
Surveillance	kt	15	15	**15**	15	15	15	15	15	15

ATM Interruptions

	No. of ATM Interruptions			
	CA	MA	FA	Total
CTAS Baseline				
OVR-OVR	261	351	312	924
OVR-ARR	121	147	150	418
OVR-DEP	119	178	140	437
ARR-DEP	59	79	143	281
DEP-DEP	22	42	NA	64
ARR-ARR	42	41	NA	83
Total	625	837	745	2,207
Scenario 1 FMS Equipage				
OVR-OVR	290	304	300	894
OVR-ARR	130	127	147	404
OVR-DEP	135	154	140	429
ARR-DEP	64	70	137	271
DEP-DEP	27	37	NA	64
ARR-ARR	48	35	NA	83
Total	694	727	724	2,145
Scenario 2 Data Exchange				
OVR-OVR	364	110	132	606
OVR-ARR	134	44	69	247
OVR-DEP	159	64	80	303
ARR-DEP	62	24	55	141
DEP-DEP	46	18	NA	64
ARR-ARR	70	12	NA	82
Total	834	273	337	1,444

Reduced Total Interruptions

- 34% Interruption Reduction, mostly from Scenario 2 Data Exchange
- 55% False Alert (FA) reduction
- 67% Missed Alert (MA) reduction
- CA increased with reduction in MA
- Largest improvement in Arr-Dep interruptions
- Assumed no interstream(A-A/D-D) interruption improvement

Interruptions Comparison with Previous Research

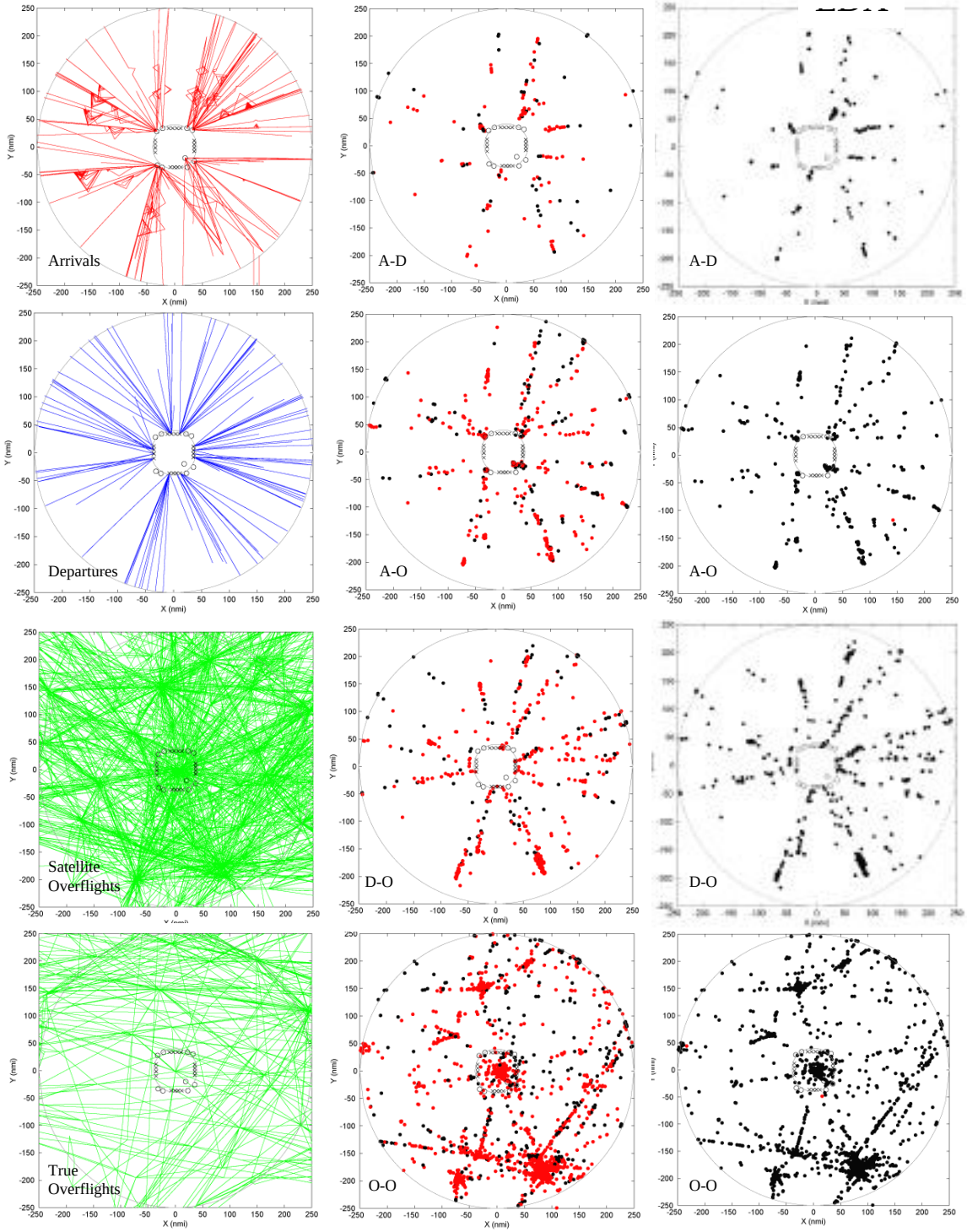
	DFW			CLE (1)
	EDA	EDX4	CPTP [MBC98]	Boeing [WE98]
OVR-OVR	42%	42%	33%	17%
OVR-ARR	19%	17%	23%	32%
OVR-DEP	20%	21%	24%	24%
ARR-DEP	13%	10%	6%	13%
DEP-DEP	3%	4%	3%	8%
ARR-ARR	4%	6%	11%	5%
Total	100%	100%	100%	100%
No. Interrupts	2,207	1,444	204	965

(1) Assumes flight mode (climb, cruise, descent) not ops type categories

Interruptions in Plan View

Trajectories **ATM Interruptions**

Baseline EI EDX



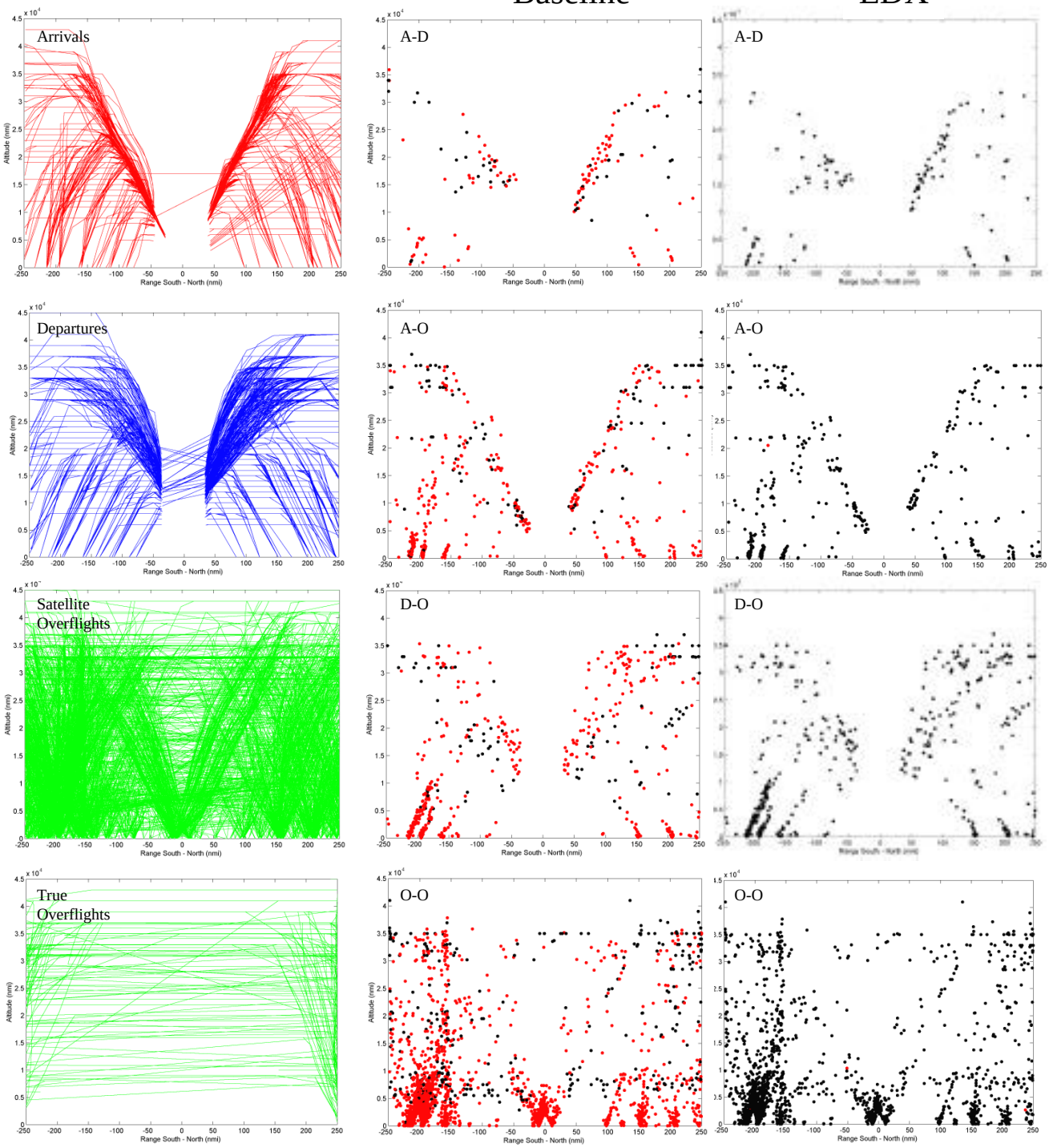
LEGEND: Correct Alert ( ) Missed Alert ( ) False Alert (o)

Note: Only Interrupts with > 50% Probability of Conflict shown

Interruptions in Profile View

Trajectories | **ATM Interruptions**

Baseline | EDX



LEGEND: Correct Alert ( ) Missed Alert ( ) False Alert (o)

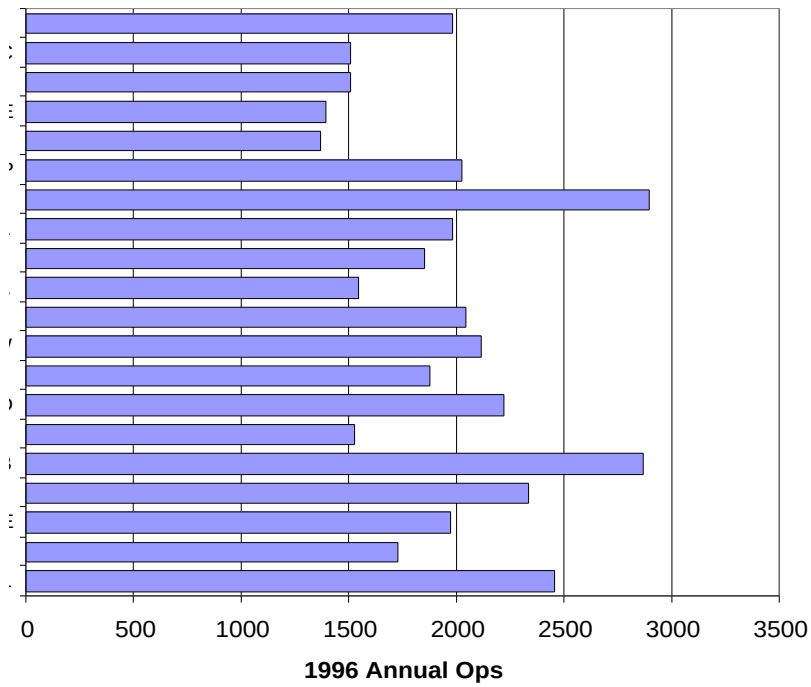
Note: Interruptions below FL100 not assessed.

1996 NAS Annual Benefits Extrapolation

Annual Cost = (Annual Ops) x (Interrupt Rate) x (Cost Per Interrupt)

- Assume CTAS & FMS Data Exchange at 43 US airports
- 1996 Annual ARTCC Operations

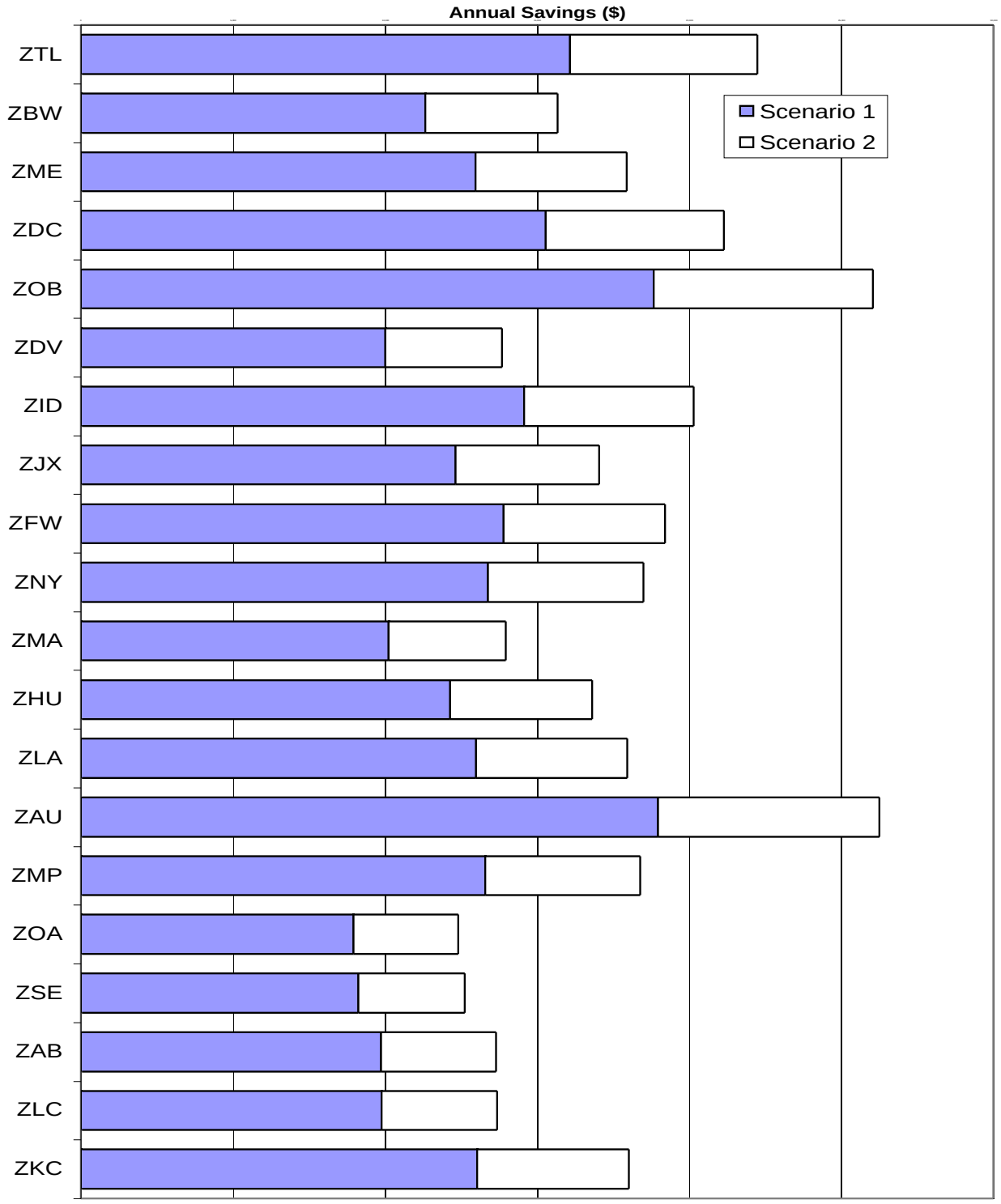
ARTCC	Airports
ZTL	ATL, CLT
ZBW	BDL, BOS
ZME	BNA
ZDC	BWI, DCA, IAD
ZOB	CLE, DTW, PIT
ZDV	COS, DEN
ZID	CVG, SDF
ZJX	DAB, MCO
ZFW	DFW
ZNY	EWR, HPN,JFK,LGA,PHL,TEB
ZMA	FLL, MIA
ZHU	HOU, IAH
ZLA	LAS, LAX, LGB, SAN
ZAU	MDW, ORD
ZMP	MSP
ZOA	OAK, SFO
ZSE	PDX, SEA
ZAB	PHX
ZLC	SLC
ZKC	STL



- Interrupt Rates
  - Baseline - 35.7 interrupts/100 ops
  - FMS - 34.7
  - Data Exchange - 23.2

NAS Benefit Estimate

Annual Cost = (Annual Ops) x (Interrupt Rate) x (Cost Per Interrupt)



Findings & Recommendations

Findings:

- **Method to Evaluate Conflict Probe Performance Benefits**
- **En Route Data Exchange can improve CP Performance, especially in reducing missed and false alerts**

Recommendations:

- **Improve Trajectory Parameter Accuracy Values**
  - Review/revise parameter assumptions, use airline data
  - Develop model to link accuracy components to position error for cruise/climb/descent trajectories
- **Improved Cost Model**
- **Additional Traffic Avoidance Resolution Strategies**
- **Multiple Initial Conditions**
- **Sensitivity Analyses**