A simple method to integrate Mode S Indicated Airspeed with Ground Based Trajectory Prediction

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London & Scottish FIRs:
1m km² – 11% of Europe’s airspace and 25% of traffic

Shanwick
2.2m km² – 80% of North Atlantic traffic
**Prestwick Centre**
Handles on average 2,500 flights/day
- Scottish Oceanic Control Centre
- Scottish Area Control Centre
- Manchester Area Control Centre

**Swanwick Centre**
Handles on average 5,500 flights/day
- London Area Control Centre
- London Terminal Control Centre
- London Military Air Traffic Control

**Head Office**
Corporate & Technical Centre
- College and Training centre
- Engineering
- AQUILA
- Support functions
Controller Tools at NATS

![Separation Monitor Diagram]

- **Closest approach distance**
- **Time to interaction**

### Key

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="catch-up.png" alt="Catch-up" /></td>
<td>Catch-up: 5 Nm or more between tracks is assured by setting heading or speeds.</td>
</tr>
<tr>
<td><img src="head-on.png" alt="Head-on" /></td>
<td>Head-on: 5 Nm or more predicted but not assured.</td>
</tr>
<tr>
<td><img src="crossing.png" alt="Crossing" /></td>
<td>Crossing: less than 5 Nm predicted between tracks when uncertainty taken into account, but 5 Nm or greater when considering nominal positions.</td>
</tr>
<tr>
<td><img src="catch-up.png" alt="Catch-up" /></td>
<td>Catch-up: less than 5 Nm between tracks.</td>
</tr>
</tbody>
</table>

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Controller Tools at NATS

Flight level

Down track distance

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Controller Tools at NATS

Radar Track

Clearance

Flight Plan

Trajectory Prediction

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Separation Monitor

![Graph showing separation (nm) over time (min)]
Separation Monitor

- Separation (nm): 0, 5, 10, 15
- Time (min): 0, 1, 2, 3, 4, 5, 6, 7, 8

Diagram showing separation over time.
Separation Monitor

- separation (nm)
  - 0
  - 5
  - 10
  - 15
- time (min)
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8

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Controller Tools at NATS

Tools show the closest approach point and the time to go for each interaction

Better Prediction

Better Interactions

Lower Workload

Increased Capacity

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Trajectory Prediction Algorithm

- Based on Eurocontrol BADA 3 Total Energy Model
- Constant Calibrated Airspeed (CAS) Climb

1. Determine CAS
2. Calculate TAS
3. Calculate ROCD
4. Calculate Vx
5. Calculate GSpd
6. New Altitude
7. Combining Prediction
8. Lateral Position
9. Initial Position & Altitude

Wind
Speed Profile

Mode S Indicated Airspeed (IAS)

B777-200
Heathrow (UK) to Kotoka (Ghana)
Research Aim

Improve climb profile prediction by including Mode S IAS to estimate Climb CAS
4 Options

1. Stable CAS (S-CAS)
2. Low Pass Filter (LPF)
3. Growing Mean Average (GMA)
4. Kalman Filter
1. Stable CAS
2. Low Pass Filter

![Graph showing time vs predicted CAS (knots) with legends for BADA, IAS, and LPF.](image-url)
3. Growing Mean Average
4. Kalman Filter

![Graph showing predicted CAS (knots) over time.](image)

- **BADA**
- **IAS**
- **Kalman**

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Method

- NATS Database
  - Radar Data
  - Flight Plans
  - Met Data
  - BADA
  - ATC Clearances

- Filtering Criteria (a)

- Valid Segment Detection (b)

- Trajectory Prediction (c)

- Error Analysis (d)

MATLAB
Dataset

Dataset for a busy day in the London FIR
Climb portions only leaving from UK airport
Furthermore:
- Above 10,000ft (250KIAS restriction)
- Below CAS-Mach transition
- Minimum length of 30 seconds

Results in 2,219 segments over 715 flights

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Results

- 2,219 segments
- 6 different trajectory predictions per radar return in a segment
  - BADA, raw IAS & 4 Options
- 4 metrics
  - Vertical Error
  - Along Track Error
  - Stability
  - Prediction Bias

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Vertical Error

VRDD – Valid Remaining Down Track Distance (m)
VRPL – Valid Remaining Prediction Lifetime (s)
Vertical Error

95th Percentile
75th Percentile
Mean
Median
25th Percentile
5th Percentile
Vertical Error Distribution

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Along Track Error

Trajectory Prediction
Radar Track
Radar Reference Point [radarPoint, radarTime]
TP Abeam Point [TPpoint, TPtime]

D, ΔT
Prediction Bias

![Graphs showing vertical and along-track bias predictions.](image)

- **Vertical Bias**
  - Overpredict Vertical Rate
  - Underpredict Vertical Rate

- **Along Track Bias**
  - Predicted to Arrive Earlier
  - Predicted to Arrive Later

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Conclusions

Analysis showed that including Mode S IAS has:
- No significant effect on vertical accuracy
- A significant, positive effect on along track accuracy
- A detrimental effect on stability
Conclusions

Solution requirements
- “Stable, Single and Scalable”
- Support future operations
- Provide the correct balance of error metrics

→ Kalman Filter provides this
- Optimum balance of accurate and stable
- Simple to implement
- Easy to expand
Future Work

- Expand this study to cover a variety of meteorological conditions and aircraft types
- Expand Kalman filter to use Mode S Vertical Rate as well as Mode S IAS
- Characterise aircraft behaviours from historical data through Machine Learning
QUESTIONS