Real-time identification of guidance modes in aircraft descents using surveillance data:
an interacting multiple model (IMM) approach

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Workshop Thematic Challenge #2 Data-driven Trajectory Prediction

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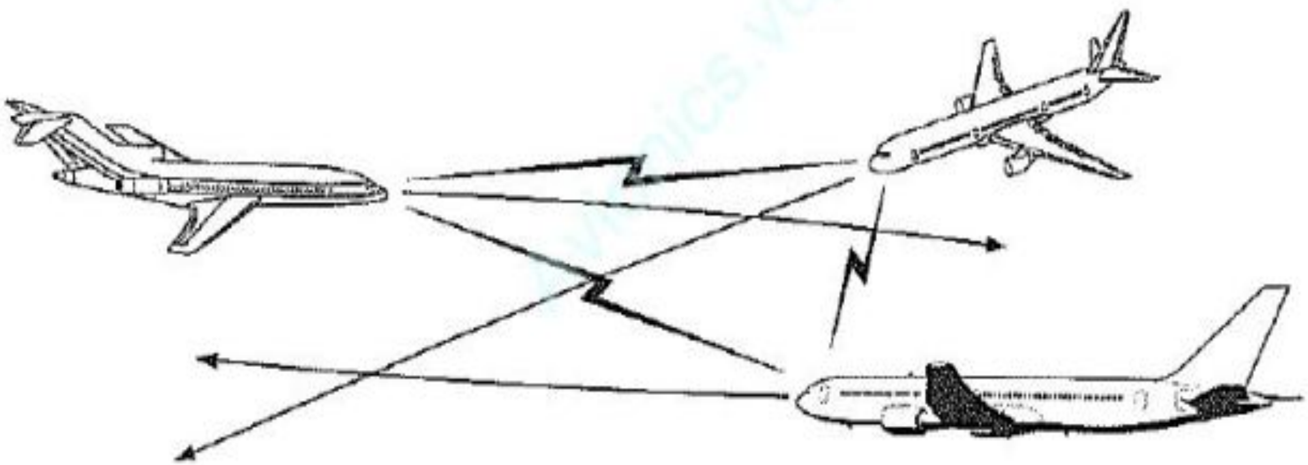
Introduction

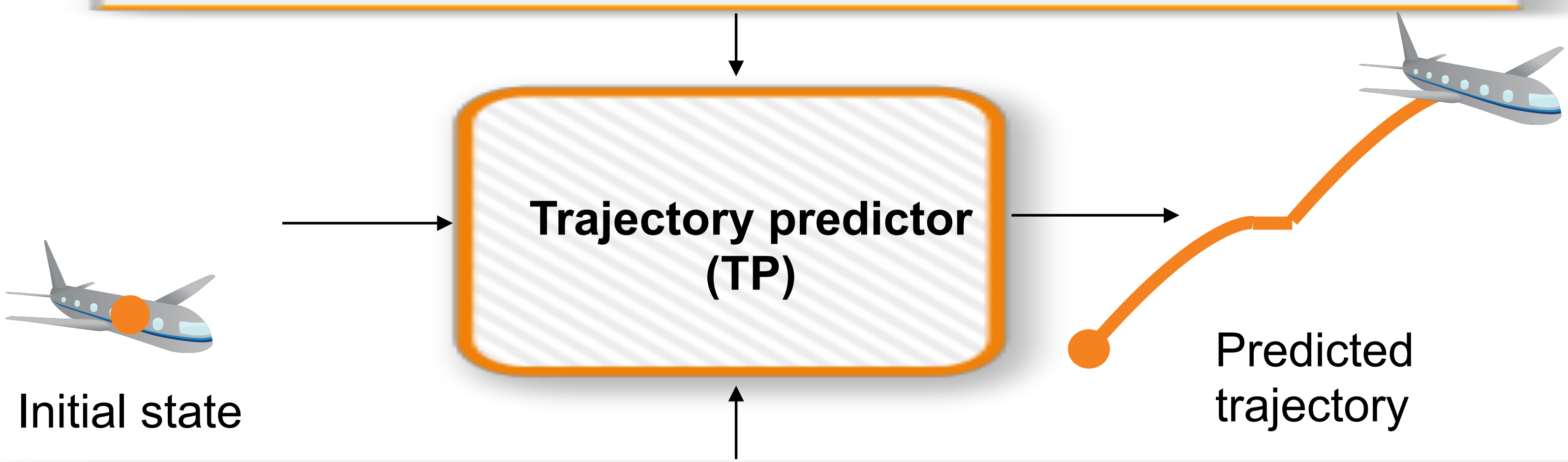
- Many **tactical** applications making use of trajectory predictors (**TPs**):
    - On-board trajectory **planning and guidance**
    - Sequencing and merging
    - On-board or ground **separation management**
    - On-board or ground **collision avoidance**
    - ….



Introduction

Model

- **Aircraft dynamics** model (e.g., point-mass model)
- **Aircraft performance** model (e.g., base of aircraft data, **BADA**)
- **Weather** model (e.g., rapid refresh forecast, **RAP**)



Flight intent

- **Guidance modes** (e.g., climb at maximum climb thrust at constant Mach)
- **Switching conditions** (e.g., up to FL100)

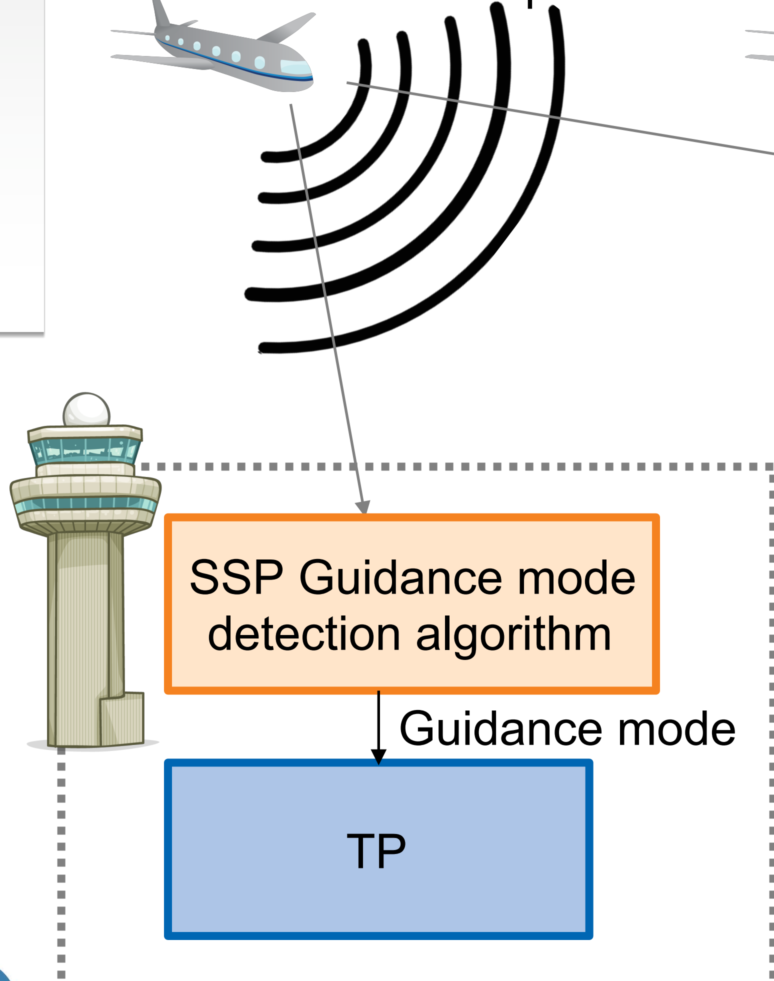
Introduction

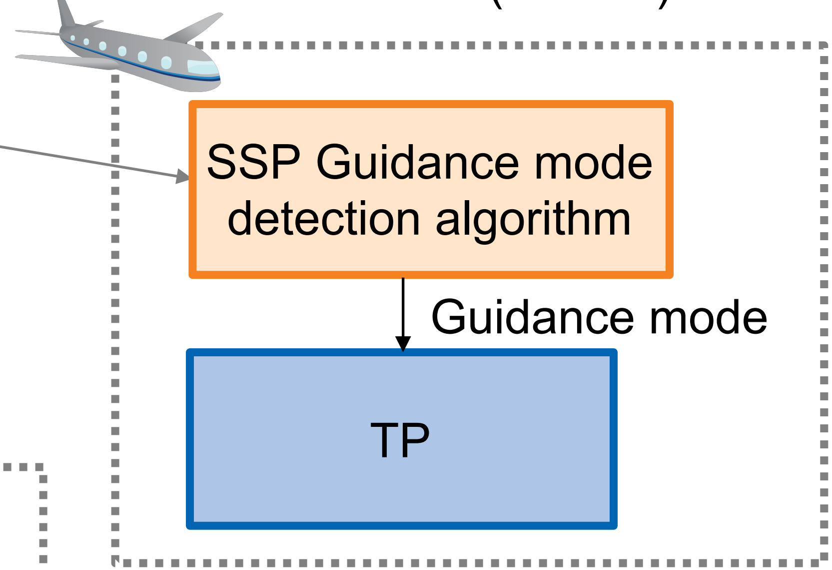
- Several works aimed at identifying simple guidance modes in the **horizontal** plane, such as coordinated turns, constant speed or acceleration segments.
- Good flight intent data is specially critical in the **vertical domain.**
- An **accurate** knowledge of flight intent is available for **ownship** TP algorithms.
- **Typical on-board** TPs for intruder trajectory prediction have a very **limited** (or non-existent) knowledge of the **intruder's flight intent**.
- **Typical ground-based** TPs typically use the Airline Procedure Model (**ARPM**), embedded in **BADA**, which tends to be **too generalist** for most applications.

Research question: Could advanced **SSP** for Next Generation TP, such as interacting multiple model (**IMM**) filters, be used to **rapidly** estimates the **guidance mode only** from **surveillance data?**

Introduction

- **Mode-S** data
- Automatic Dependent Surveillance-Broadcast (**ADS-B**) data



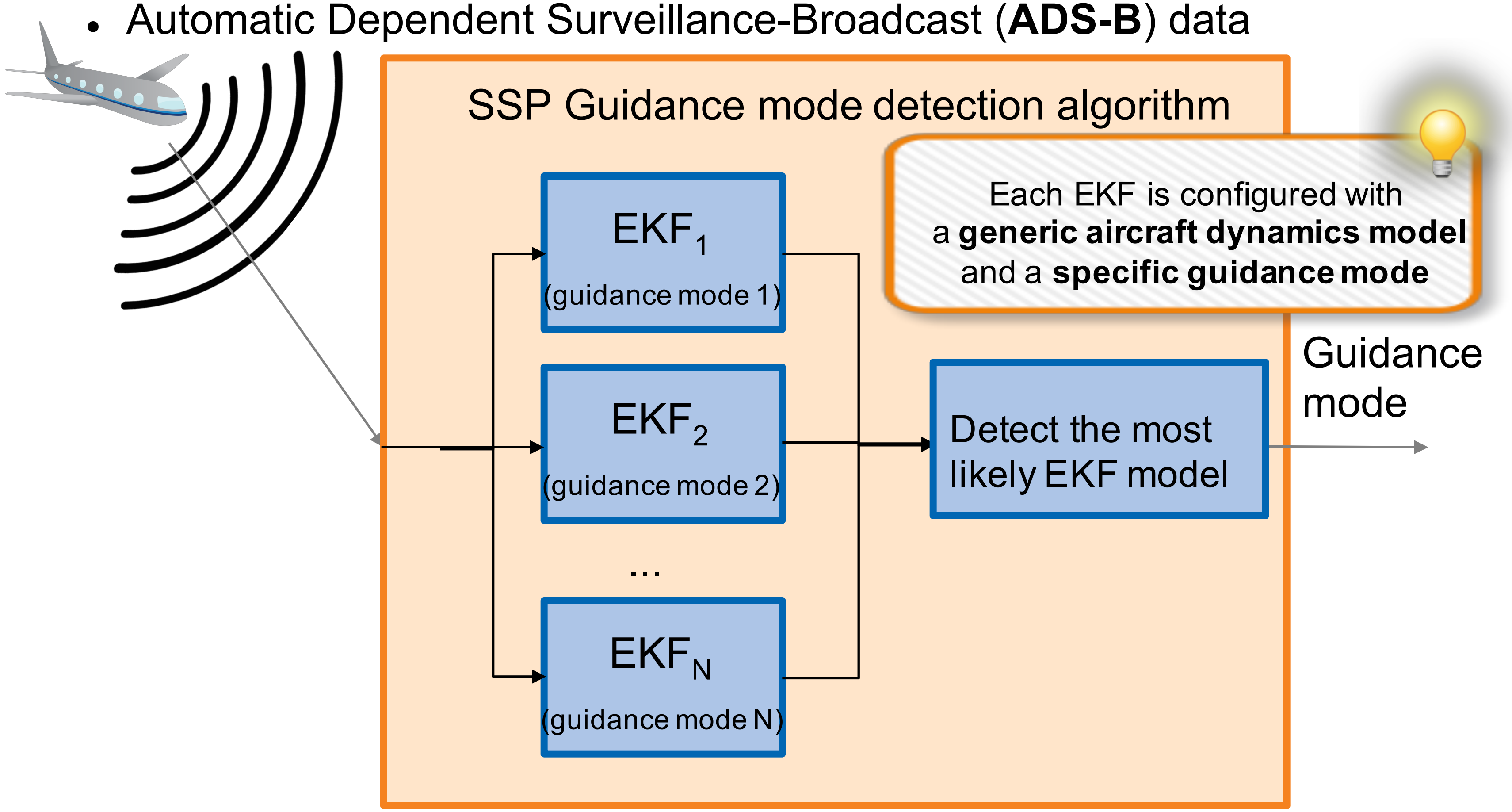


Potential **applications**:

- Accurate and reliable **guidance mode** data to any kind of airborne or ground-based **TP**
- ATM performance studies and ATM analytics

Introduction

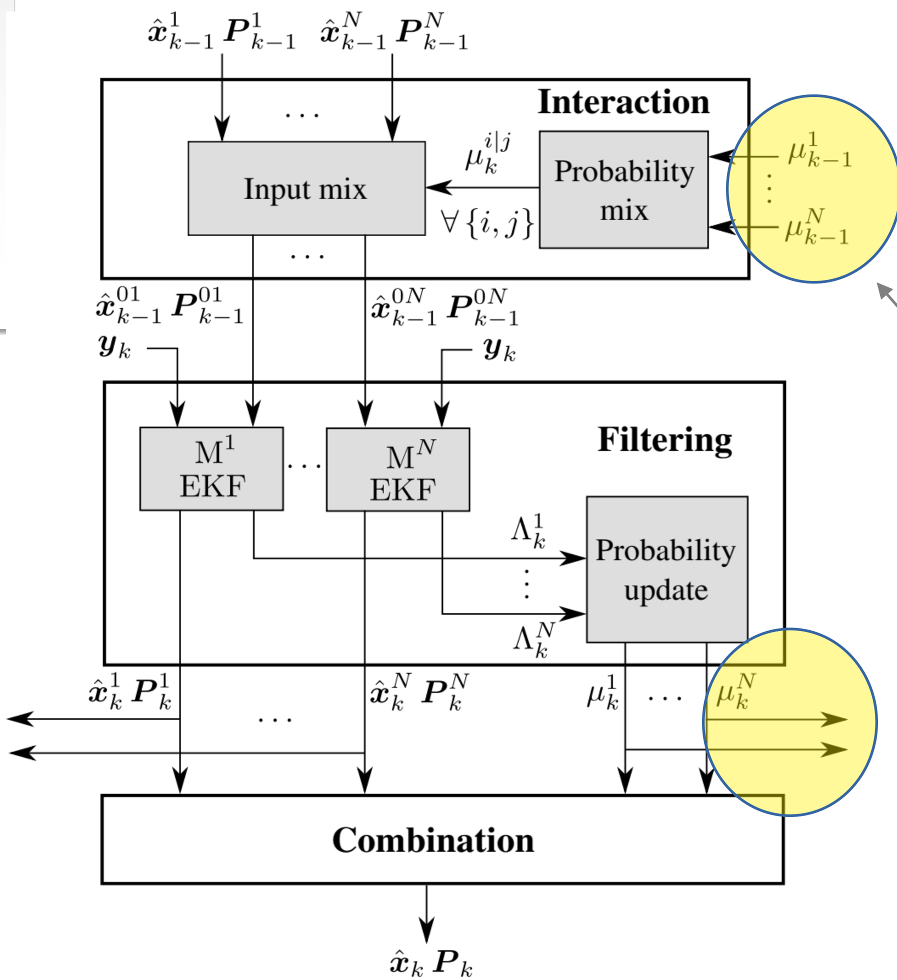
- **Mode-S** data
- Automatic Dependent Surveillance-Broadcast (**ADS-B**) data



EKF: Extende Kalman Filter

Background

The basic idea of the interacting multiple model EKF (**EKF-IMM**) is to assume a set $\mathcal{M}$ of N models as possible candidates of the true model at each time instant



Probabilistic approach:
Probability of model j being the "true" model at time k

Dalmau, R., Pérez-Batlle, M. And Prats. X. "**Real-time identification of guidance modes in aircraft descents using surveillance data**", AIAA/IEEE 37th Digital Avionics Systems Conference (DASC). September 2018. London, UK

Background

Point-mass aircraft dynamics model as a system of ordinary differential equations (**ODE**)

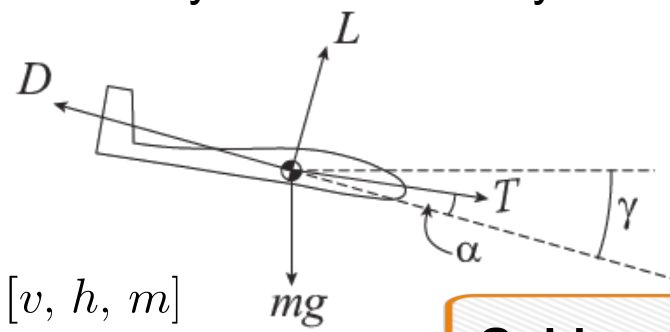
$$\frac{\mathrm{d}v}{\mathrm{d}t} = \dot{v} = \frac{T-D}{m} - g\sin\gamma$$

$$\frac{\mathrm{d}h}{\mathrm{d}t} = \dot{h} = v\sin\gamma$$

$$\frac{\mathrm{d}m}{\mathrm{d}t} = \dot{m} = -FF$$

$$\boldsymbol{x} = [v,\, h,\, m]$$

$$\boldsymbol{u} = [T,\, \gamma]$$



Guidance mode!

Two degrees of freedom of the ODE are closed by two path constraints in the form of **algebraic equations** **(1st associated with elevator, 2nd with throttle)**

$$\mathrm{c}_i\left(\boldsymbol{x},\, \boldsymbol{u},\, \boldsymbol{p}\right) = 0; \quad i \in \{1,\ 2\}.$$

Trajectory obtained by numerically integrating the resulting system of algebraic differential equations (**DAE**), ODE + path constraints, using e.g, Runge-Kutta

t: time
v: True Airspeed (TAS)
h : altitude
γ : aerodynamic flight path angle

FF: Fuel flow
T: Thrust
D : Drag
m : mass

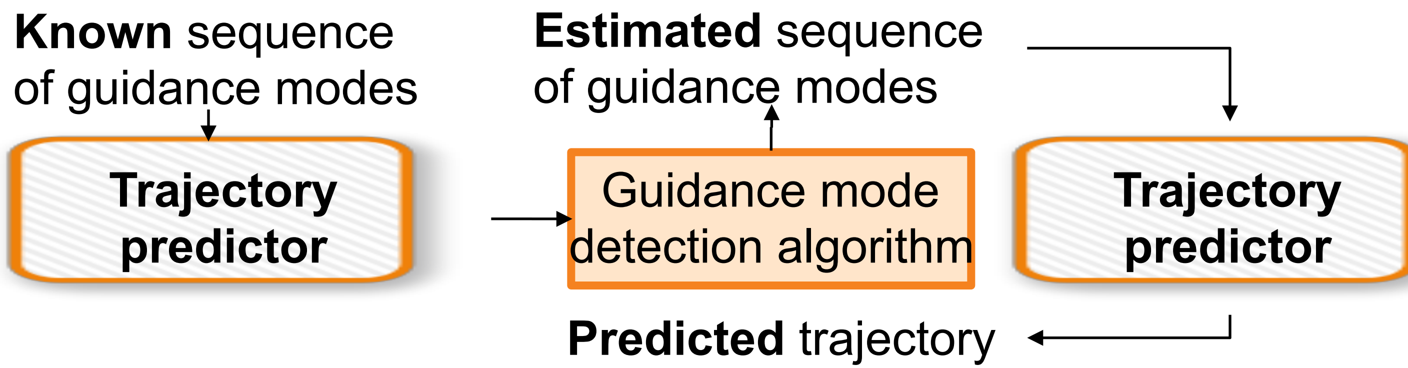
M : Mach number
v_{CAS} : Callibrated airspeed (CAS)

Application

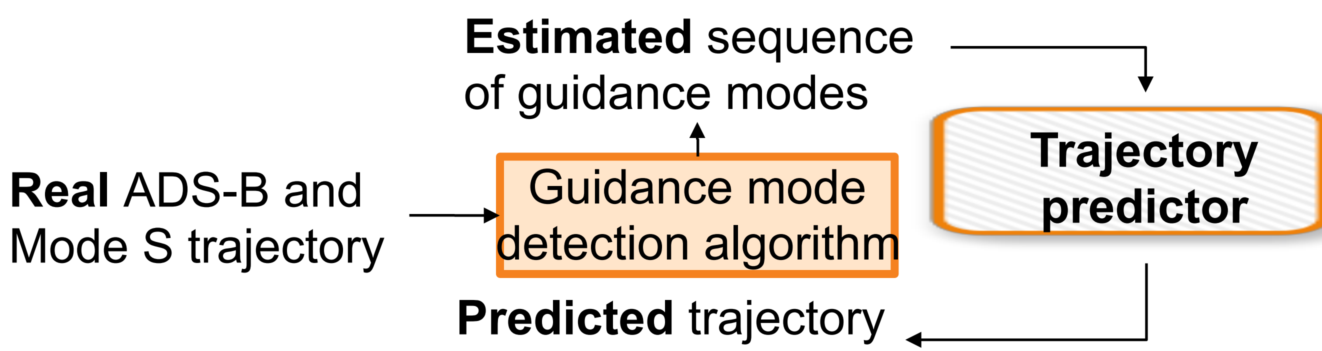
Set	M	Elevator	Throttle
1	MACH-THR	$k = k\|_{\dot{M}=0.0}$	$\pi = 0.0$
	CAS-THR	$k = k\|_{\dot{v}_{CAS}=0.0}$	$\pi = 0.0$
	DEC-THR	$k = 0.3$	$\pi = 0.0$
	ACC-THR	$k = 1.7$	$\pi = 0.0$
2	VS-MACH	$\mathrm{VS} = -1000\,\mathrm{ft\ min}^{-1}$	$k = k\|_{\dot{M}=0}$
	VS-CAS	$\mathrm{VS} = -1000\,\mathrm{ft\ min}^{-1}$	$k = k\|_{\dot{v}_{CAS}=0.0}$
	VS-DEC	$\mathrm{VS} = -1000\,\mathrm{ft\ min}^{-1}$	$k = 0.3$
	VS-ACC	$\mathrm{VS} = -1000\,\mathrm{ft\ min}^{-1}$	$k = 1.7$
	FPA-MACH	$\gamma_g = -3.0^\circ$	$k = k\|_{\dot{M}=0.0}$
	FPA-CAS	$\gamma_g = -3.0^\circ$	$k = k\|_{\dot{v}_{CAS}=0.0}$
	FPA-DEC	$\gamma_g = \quad 3.0^\circ$	$k = 0.3$
	FPA-ACC	$\gamma_g = -3.0^\circ$	$k = 1.7$
	ALT-SPEED	$\mathrm{VS} = 0.0$	$k = 0.0$
3	VS-THR	$\mathrm{VS} = -1000\,\mathrm{ft\ min}^{-1}$	$\pi = 0.0$
	FPA-THR	$\gamma_g = -3.0^\circ$	$\pi = 0.0$
	ALT-THR	$\mathrm{VS} = 0.0$	$\pi = 0.0$

Results

1) Algorithm **validation**: Airbus Performance Engineering Program (**PEP**) has been used to synthetize two representative trajectories using realistic performance data with a known sequence of guidance modes

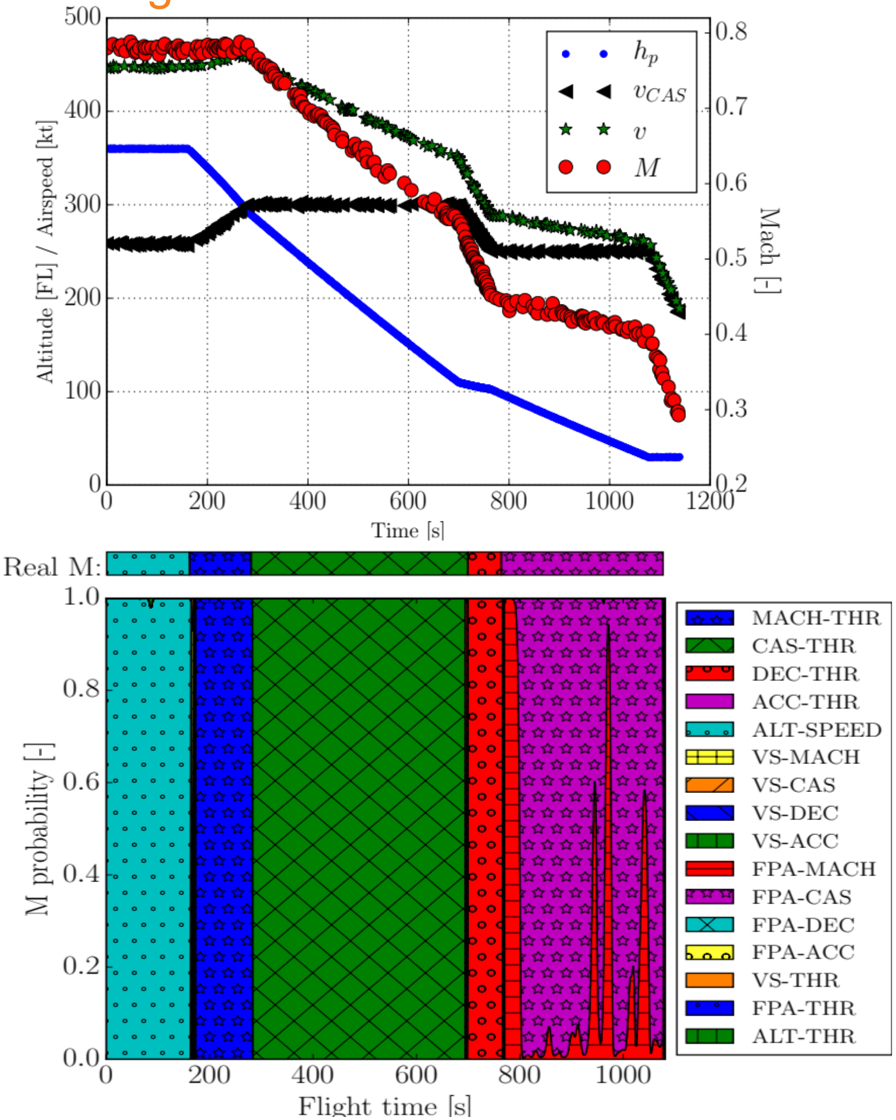


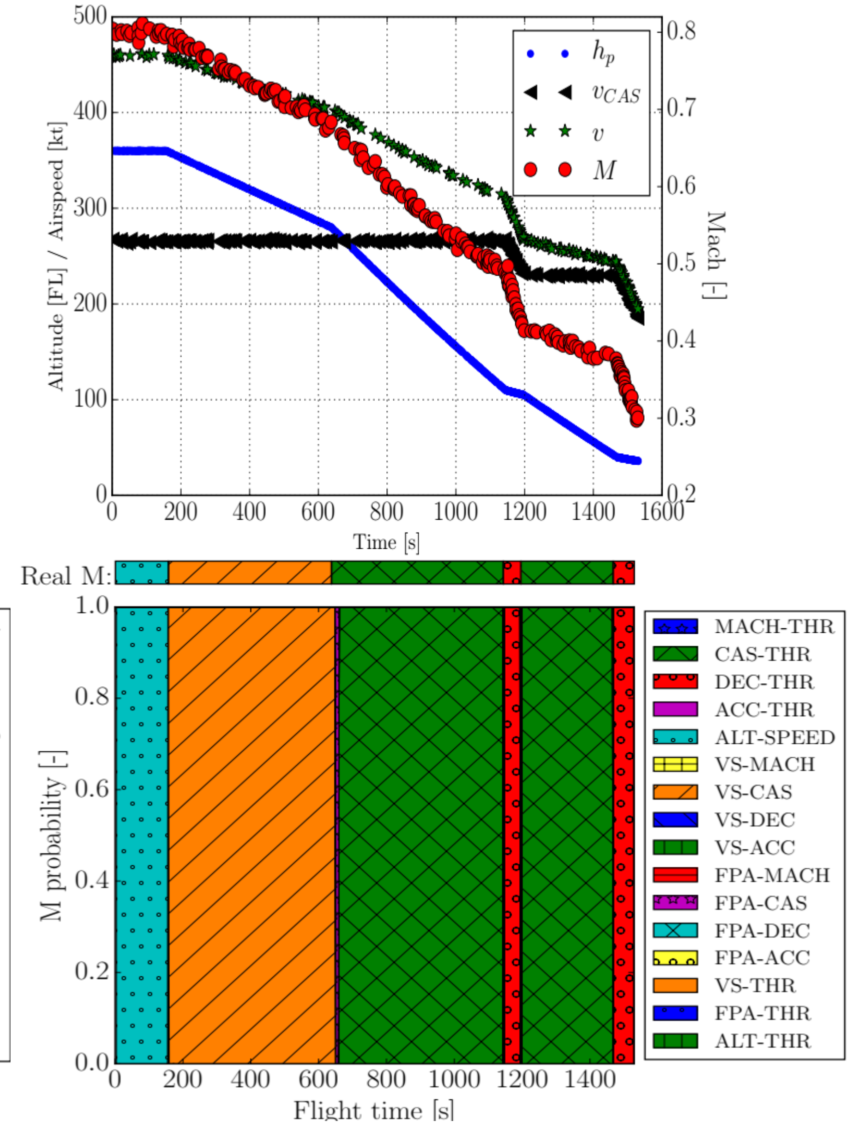
2) Case study with **real flight data**: application example where the guidance modes are identified from **ADS-B** and **Mode S** messages



Results

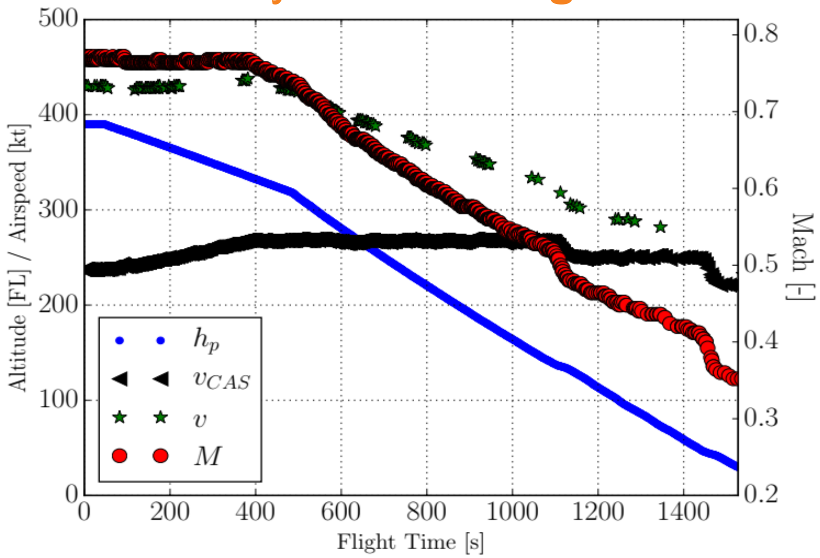
Algorithm **validation**:

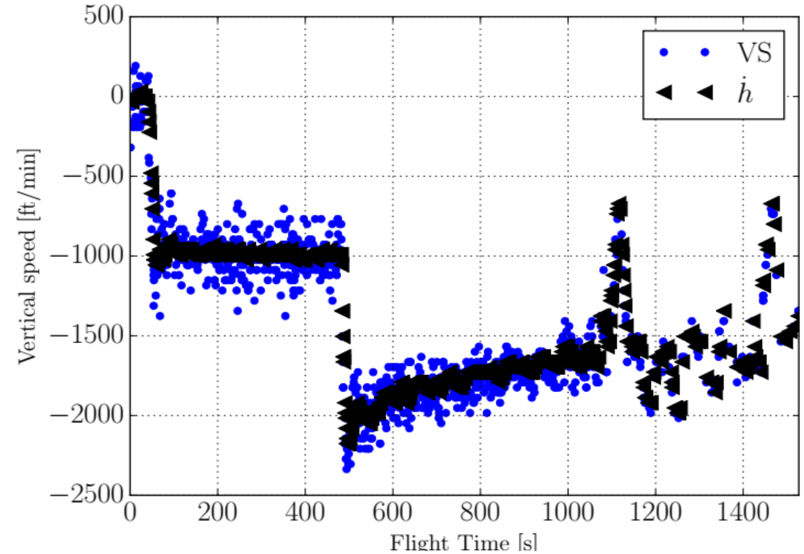


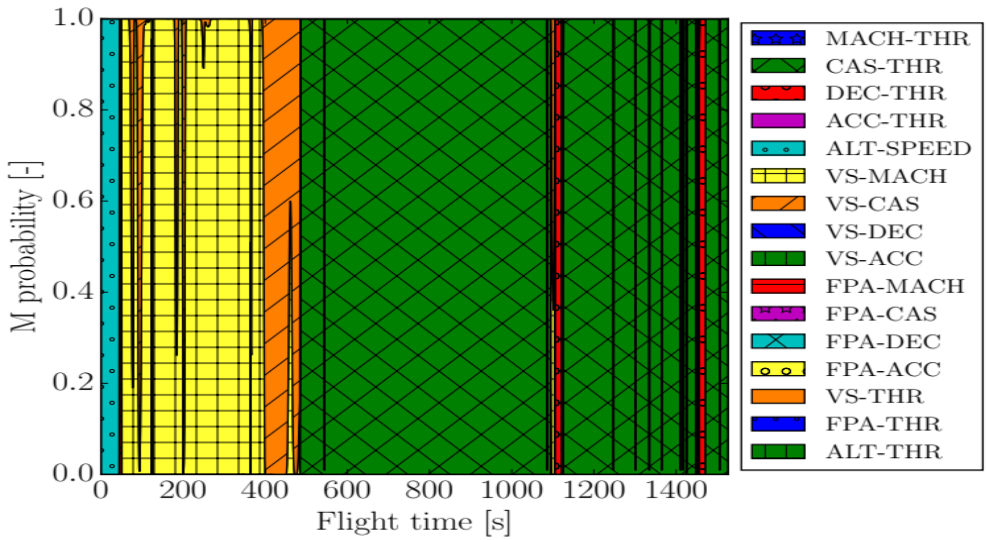


Results

Case study with **real flight data**:







Conclusions

- Advanced **SSP** for Next Generation TPs, such as the Interacting multiple-model (**IMM**) algorithm, could be used to identify the actual **guidance mode** of aircraft from broadcast surveillance data.

- The guidance mode could be **identified** almost **instantaneously (useful for real-time predictions)** using **IMM**

- Advanced **SSP** could support a wide range of air traffic management (**ATM**) applications and tools that require on-board or ground-based accurate **trajectory predictors** and **conflict detection** and **resolution** algorithms

Further research

- Further research might focus on estimating not only the guidance modes, but also the **switching conditions** between consecutive guidance modes

- Results from both validation and case study assumed ideal trajectories with **clearly defined guidance modes** fitting with some model of the EKF-IMM. In practice, more complex aircraft behaviors could be found.

- **Fixed parameters** were considered, which might not be representative of the behavior of **ALL** types of aircraft in **ALL** possible maneuvers.

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	CAS THR	$k = k\|_{\dot{v}_{CAS}=0.0}$	$\pi = 0.0$
	DEC THR	$k = 0.3$	$\pi = 0.0$
	ACC THR	$k = 1.7$	$\pi = 0.0$
2	VS MACH	$VS = 1000\,\text{ft min}^{-1}$	$k = k\|_{\dot{M}=0}$
	VS-CAS	$VS = -1000\,\text{ft min}^{-1}$	$k = k\|_{\dot{v}_{CAS}=0.0}$
	VS-DEC	$VS = 1000\,\text{ft min}^{-1}$	$k = 0.3$
	VS ACC	$VS = -1000\,\text{ft min}^{-1}$	$k = 1.7$
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	ALT-THR	$VS = 0.0$	$\pi = 0.0$

Thank you, any question?