

UTOPIA

UNIVERSAL TRAJECTORY SYNCHRONIZATION FOR HIGHLY PREDICTABLE ARRIVALS ENABLED BY FULL AUTOMATION

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Outline

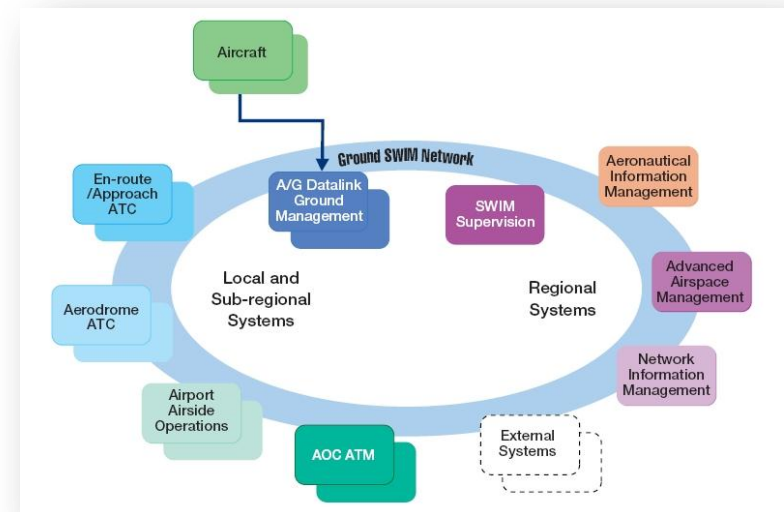
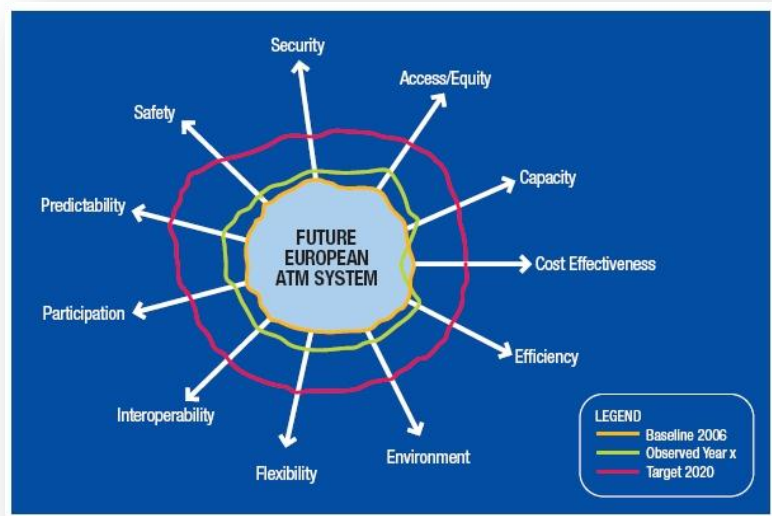
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- UTOPIA in the SESAR Context
- Team and Goals
- Uncertainty Main Sources: Flight Plan / Trajectory and Environment
- The Concept Vision
- Uncertainty - Preliminary Modeling
- Trajectory Data Synchronization Elements - Preliminary Modeling
- Proof of Concept Strategy

Thematic Introduction

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- UTOPIA responded to the CFT of SESAR – WP E in the theme:
“Towards Higher Levels of Automation in ATM” scoping towards:
 - Exploring novel modeling techniques to ... solve critical procedural issues of future ATM scenarios [WP E Information day July 2010]
- In light of SESAR Performance Targets KPA set out in “D2” and “D3”
UTOPIA aims at complementing SESAR activities of WP 1-11 by focusing on innovative research for *formal models for (uncertain) trajectory data synchronization*



The Team – The Goal

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- UTOPIA is:



(Lead)



- The solution proposed in UTOPIA is articulated by three innovative key elements:
 - study **uncertainty sources** and their propagation in the aircraft n-dimensional trajectories (nDT), considering also system disruptions
 - formal models of trajectory data and **trajectory synchronization** protocols for heterogeneous systems in an automated environment,
 - advanced **trajectory management algorithms** and ground synchronization functions based on the formal n-dimensional trajectory data and uncertainty models substituting today's HMI by **automated functions**

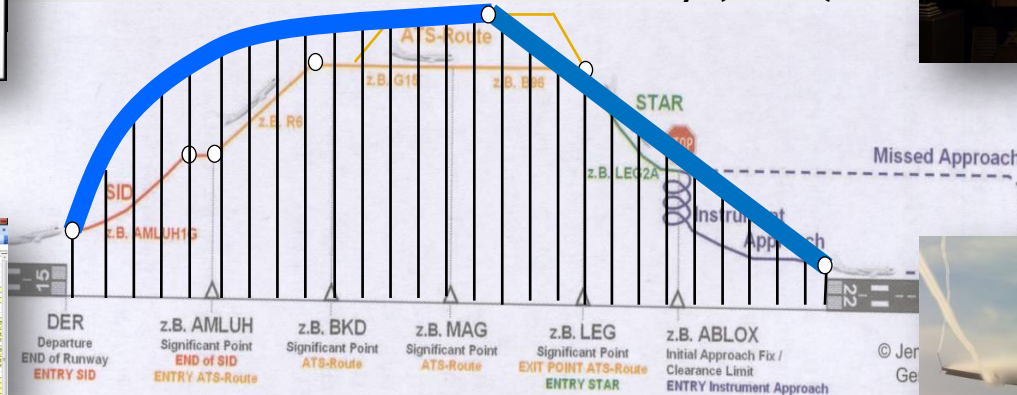
Uncertainty Modeling

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- Stochastic factor evaluation:
 - Aircraft's navigation performance (ANP) and guidance accuracy
 - Environment, e.g. random variations of the environmental factors
 - Operational factors, e.g. variability among the actual pilot/FMS actions and models



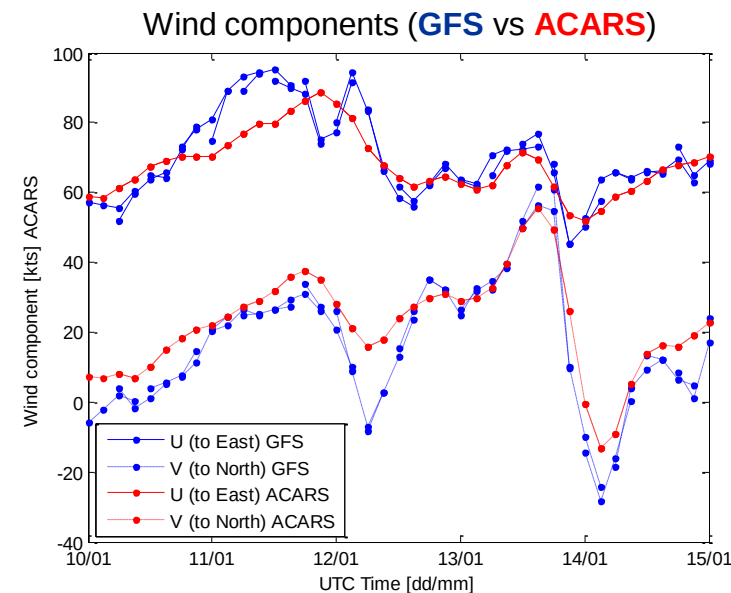
Leads to corridor of uncertainty (COU)




Uncertainty : *Atmospheric modeling*

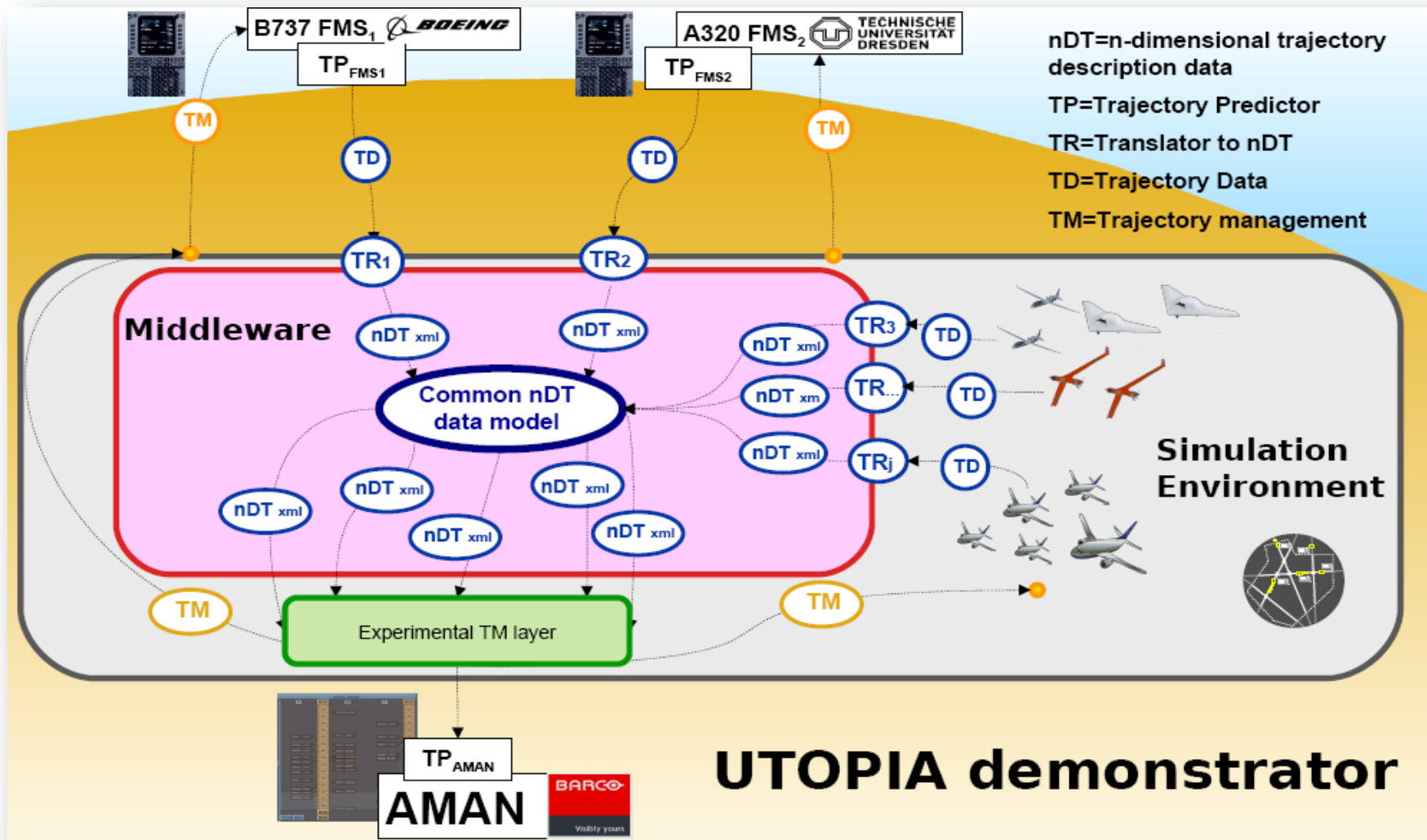
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- Predicted atmosphere for flight management system and AMAN:
 - Global Forecast System (GFS) data: 4D grid of wind, temperature and pressure
 - 6 hour **update cycle**, 4D grid **resolution** of 0.5 deg, 750 - 5000 ft, 3 hours
 - FMS:
 - Use last update cycle available few minutes before departure
 - Synchronize weather prediction with AMAN
 - AMAN: use most recent update cycle (no delay)
- Actual atmosphere:
 - Optionally based on **real aircraft measurements** from ACARS database for same dates of GFS
 - Alternative: **statistical uncertainty** superposed to GFS data



The Concept Vision: *UTOPIA demonstrator*

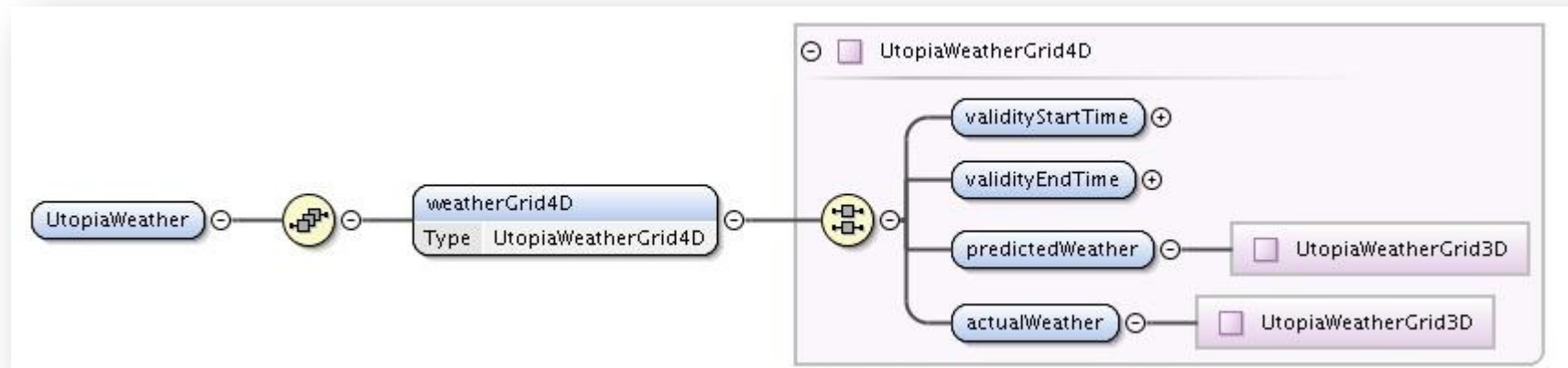
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Modeling: *handling of varying weather forecasts*

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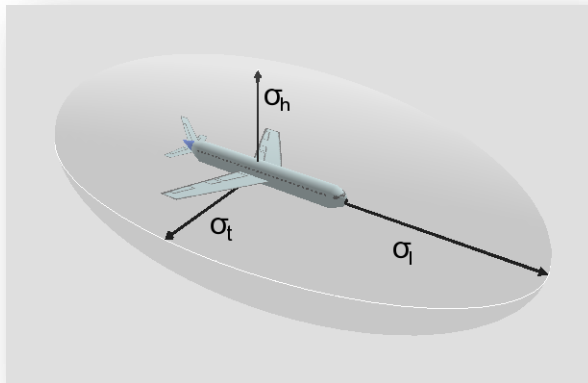
- The **UtopiaWeather** simulator message consists of a:
 - Sequence of 3D weather data with each entry valid for a specific time interval.
 - Each time interval contains *predicted* and *actual* weather data.
 - Predictors (TP, ...) use the predicted data, simulators use the actual data.
- This way varying amounts of weather **prediction uncertainty** can be simulated and evaluated.



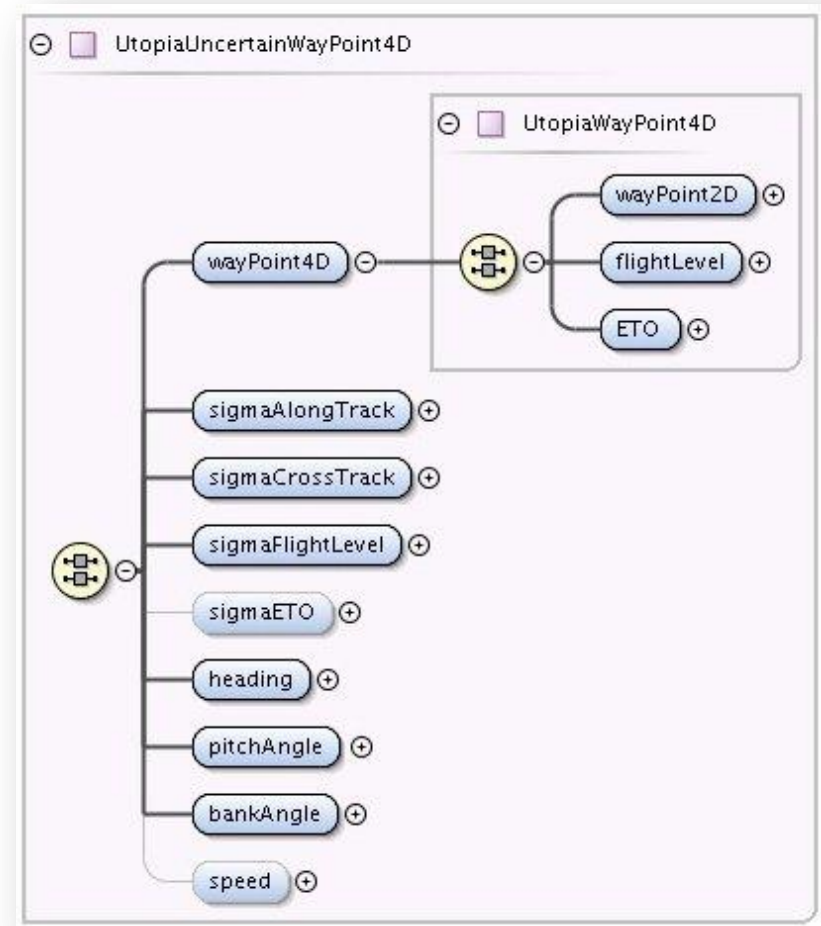
Modeling: *handling of 4D trajectory uncertainty (1/2)*

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- The **UtopiaUncertainWayPoint4D** type:
 - Uses a *3D multivariate normal distribution* to define the a/c position probability.



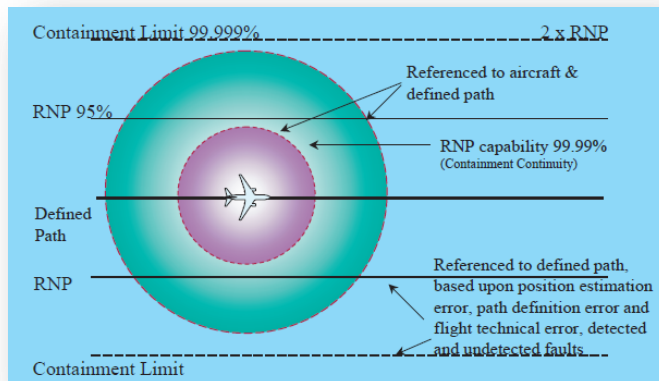
- With standard deviation values defining: along track, cross track and height uncertainty.
- Heading, climb angle and bank angle align the distribution to the a/c orientation.



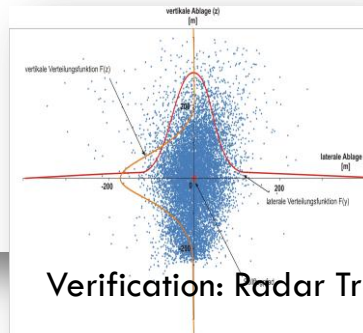
Modeling: *handling of 4D trajectory uncertainty (2/2)*

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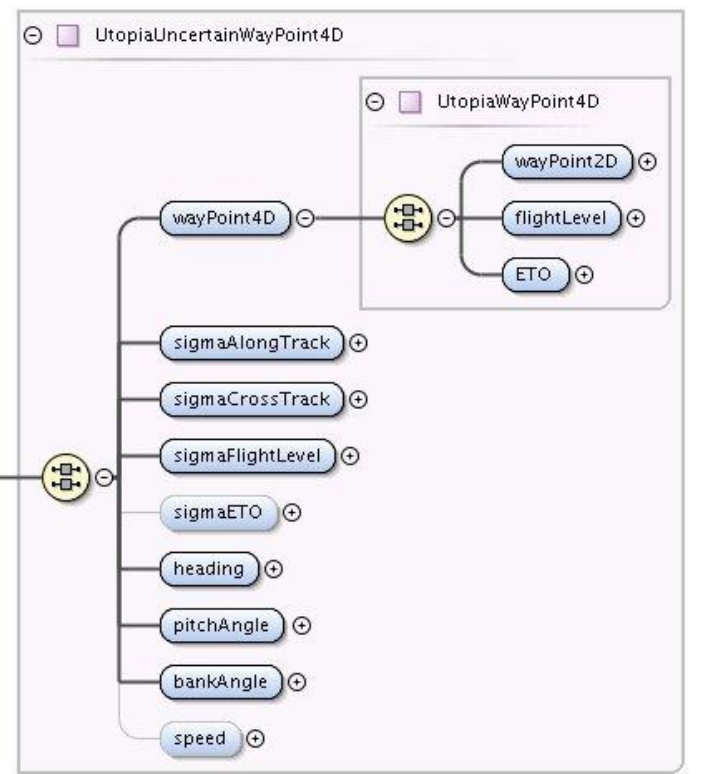
- The **UtopiaUncertainTrajectory4D** message extends the 4D trajectory to a 4D trajectory with a/c position uncertainty parameters.



Starting point: ICAO RNP/RNAV



Verification: Radar Track Analysis



Uncertainty: *BARCO - AMAN planning horizons*

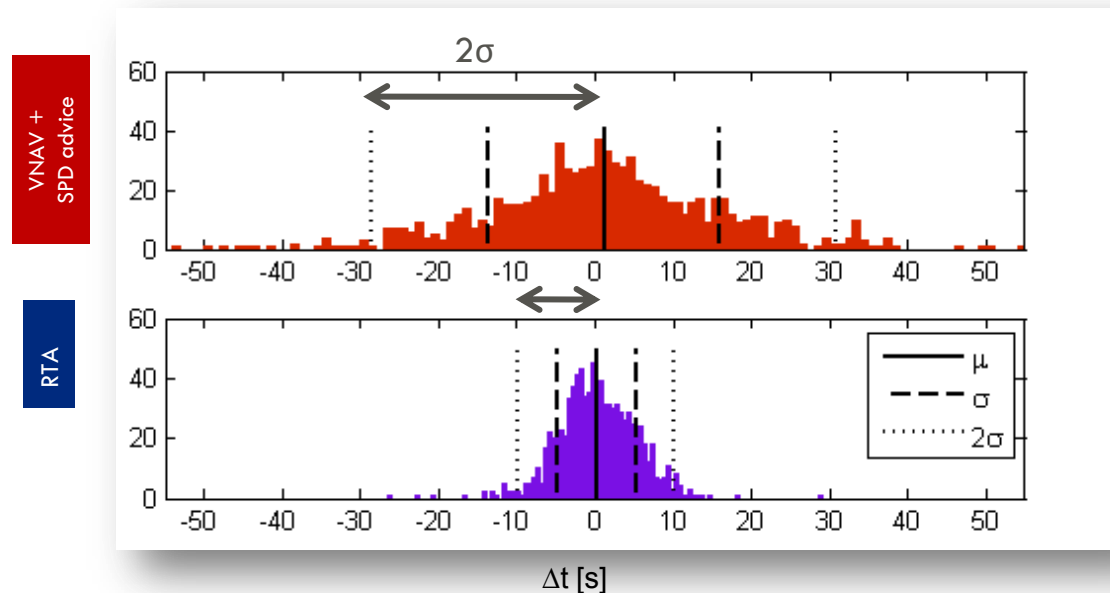
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- The OSYRIS arrival manager currently performs arrival calculations based on the following different types of information:
 - All on **pre-tactical level**:
 - **Pre-Sequencing (“quite certain”)** based on predicted FIR entry time
 - Input sources: transfer times, flight plan data or CFMU data
 - Planning horizon: 30 min - 2,5 h
 - **Sequencing (“very certain”)** based on surveillance data within FIR
 - Planning horizon: 15 - 50 minutes depending on radar coverage and FIR geometry
 - *Credo: All data is sufficiently precise to avoid trajectory discontinuities*
 - Examples for Pre-Sequencing:
 - Singapore: main ATM system FIR entry prediction extends horizon to approx. 90 min
 - London: CFMU data trigger sequencing 80 min before landing
- UTOPIA: Inclusion of **rather uncertain** trajectory data (-> **strategic level**)

Uncertainty: *BEOING* – currently achievable time accuracy

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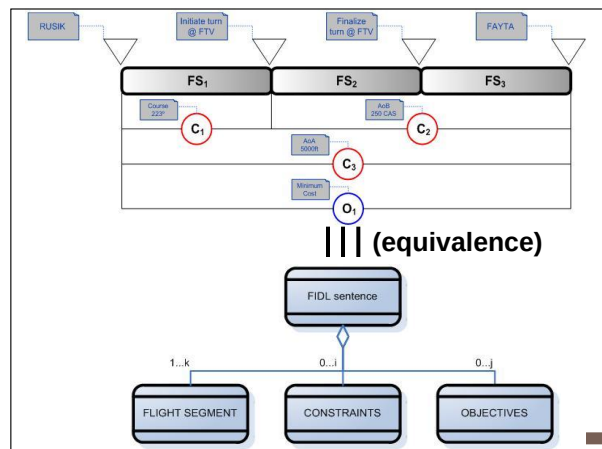
- Time delivery accuracy example - Boeing Aircraft FMS Simulation
 - Depending on onboard guidance method: VNAV with speed advisory from AMAN and RTA
 - Uncertainty in atmospheric conditions
 - Over flight time (Flight Duration) of 20 minutes



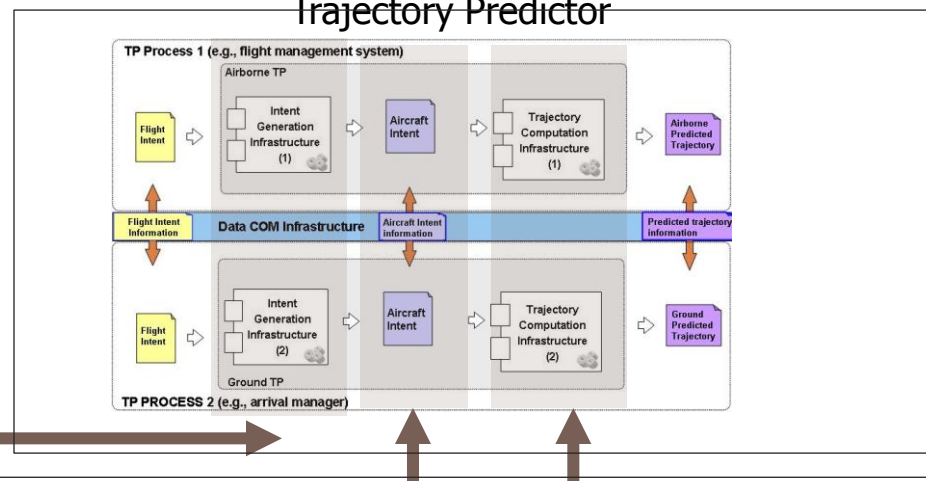
Trajectory Synchronization: *common language*

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Flight
Intent
Description
Language:
FIDL



Trajectory Predictor



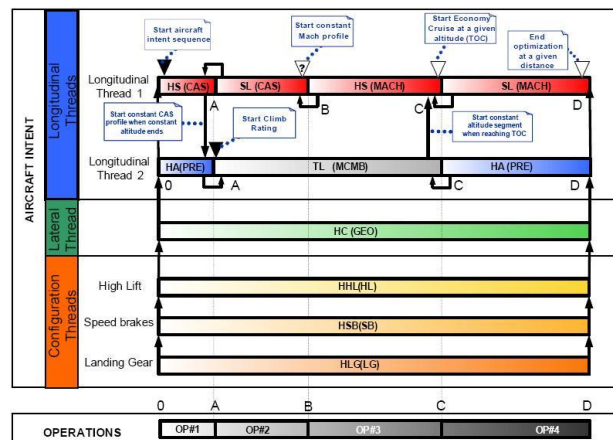
Aircraft
Intent
Description
Language:
AIDL

#	Generic mathematical formulation	Aircraft aspect affected
C1	$\delta_{HL} = c_1(X, t)$	High Lift devices
C2	$\delta_{SB} = c_2(X, t)$	Speed Brakes
C3	$\delta_{LG} = c_3(X, t)$	Landing Gear
M1	$\delta_T = g(X, E(X, t), t)$	Throttle
M2	$\mu_{TAS} = g(X, E(X, t), t)$	Bank angle
M3	$v_{TAS} = g(X, E(X, t), t)$	Speed
M4	$\gamma_{TAS} = g(X, E(X, t), t)$	Path angle
M5	$\chi_{TAS} = g(X, E(X, t), t)$	Yaw angle
M6	$h = g(X, E(X, t), t)$	Altitude
M7	$v_{TAS} \cos \gamma_{TAS} = g(X, E(X, t), t)$	Horizontal speed
M8	$v_{TAS} \sin \gamma_{TAS} = g(X, E(X, t), t)$	Vertical speed
M9	$g(\lambda, \varphi) = 0$	Horizontal track
M10	$g(\lambda, \varphi, h) = 0$	Vertical track

Constraints

#	Code	Instruction	Constraint
1	ST	Set Throttle	M1
2	TL	Throttle Law	M1
3	HT	Hold Throttle	M1
4	OLT	Open Loop Throttle	M1
5	SBA	Set Bank Angle	M2
6	BAL	Bank Angle Law	M2
7	HBA	Hold Bank Angle	M2
8	OLB	Open Loop Bank	M2
9	SL	Speed Law	M3
10	HS	Hold Speed	M3
11	SPA	Set Path Angle	M4
12	PAL	Path Angle Law	M4
13	HPA	Hold Path Angle	M4
14	CL	Course Law	M5
15	HC	Hold Course	M5
16	AL	Altitude Law	M6
17	HA	Hold Altitude	M6
18	HSL	Horizontal Speed	M7
19	HHS	Hold Horizontal	M7
20	VSL	Vertical Speed Law	M8
21	HVS	Hold Vertical Speed	M8
22	THP	Track Horizontal Path	M10
23	TVP	Track Vertical Path	M10
24	SHL	Set High Lift	C1
25	HLL	High Lift devices	C1
26	HHL	Hold High Lift	C1
27	SSB	Set Speed Brakes	C2
28	SBL	Speed Brakes Law	C2
29	HSB	Hold Speed Brakes	C2
30	OLSB	Open Loop Speed	C2
31	SLG	Set Landing Gear	C3
32	HLG	Hold Landing Gear	C3

AIDL - Instructions



Aircraft Intent Sequence

$$\frac{dv_{TAS}}{dt} = \frac{T - D - W \sin \gamma_{TAS} + W A_1}{m}$$

$$\frac{d\gamma_{TAS}}{dt} = \frac{1}{v_{TAS}} \left[\frac{L \cos \mu_{TAS} - W \cos \gamma_{TAS} + W A_2}{m} \right]$$

$$\frac{d\chi_{TAS}}{dt} = \frac{1}{v_{TAS} \cos \gamma_{TAS}} \left[\frac{L \sin \mu_{TAS} + W A_3}{m} \right]$$

$$\frac{dm}{dt} + F = 0$$

$$\frac{d\lambda}{dt} = \frac{1}{(N + h) \cos \varphi} (v_{TAS} \cos \gamma_{TAS} \sin \chi_{TAS} + w_2)$$

$$\frac{d\varphi}{dt} = \frac{1}{M + h} (v_{TAS} \cos \gamma_{TAS} \cos \chi_{TAS} + w_1)$$

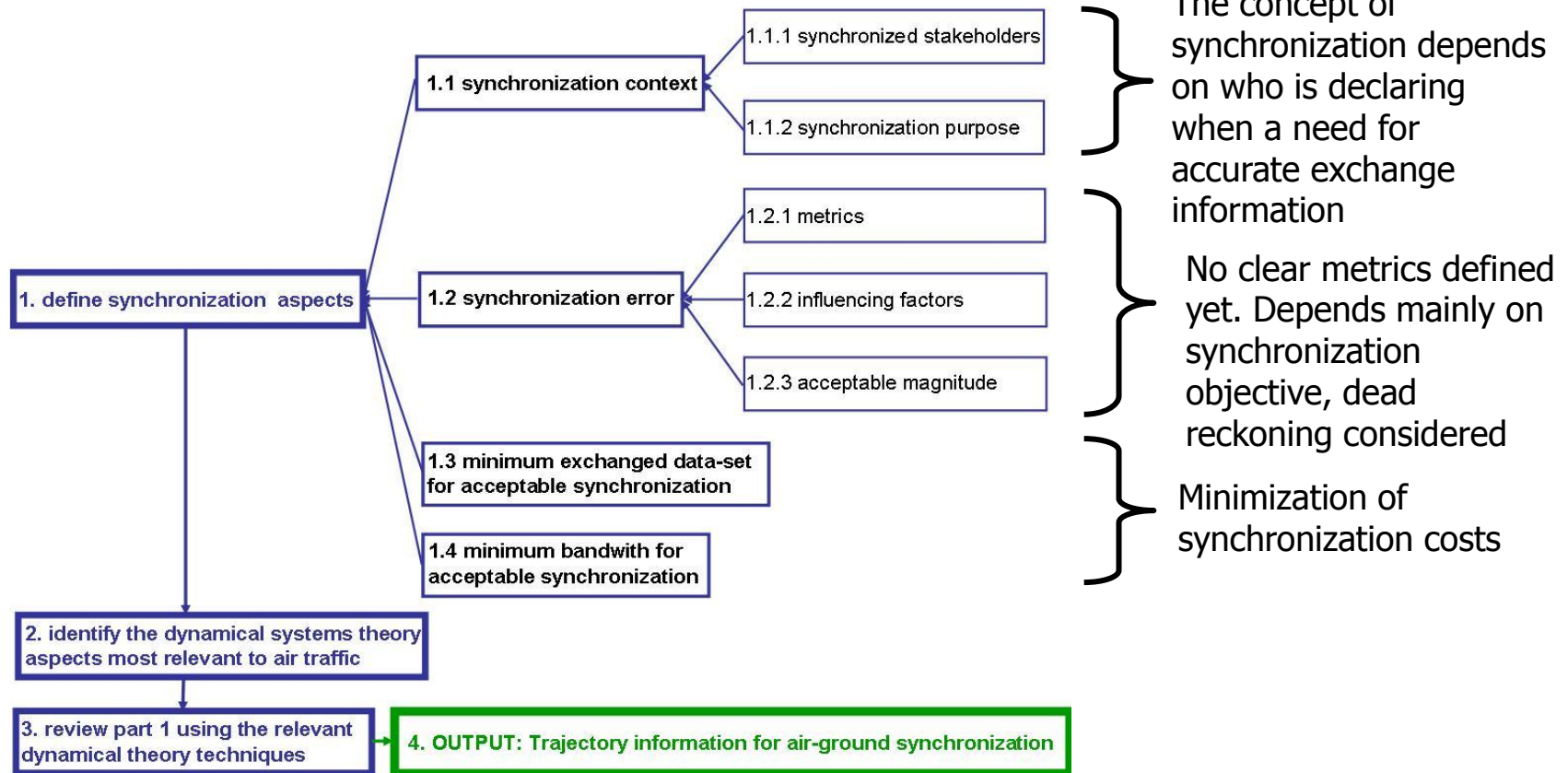
$$\frac{dh}{dt} = v_{TAS} \sin \gamma_{TAS}$$

Eq. Of Motion

Trajectory Synchronization: *Event handling*

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Define what and why do we need and how to measure the quality of results



Proof of Concept: *Uncertainty & synchronized Data handling*

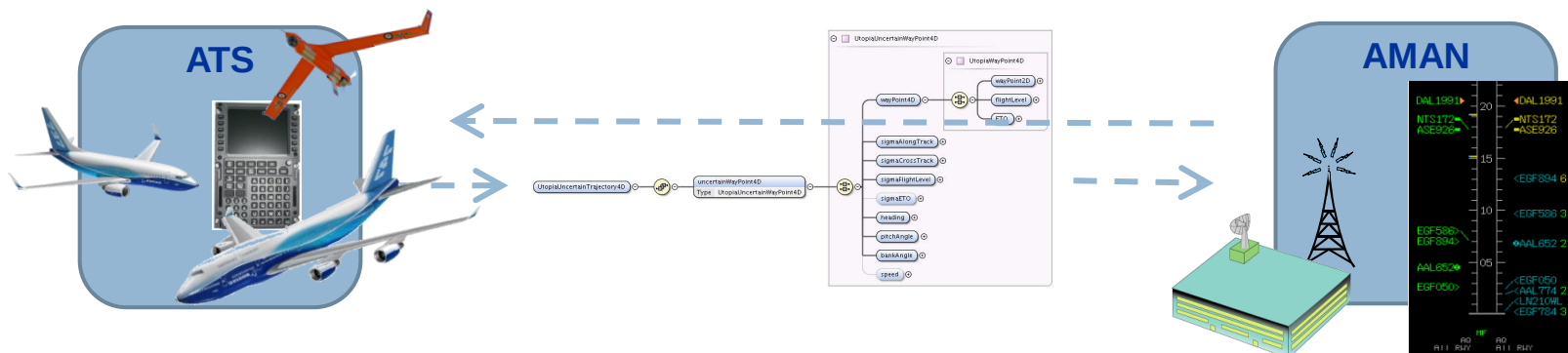
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Uncertainty

- A/C will continue to use deterministic 4 D intent information inside the FMS
- The AMAN ground system is additionally considering stochastic track information used pre-tactically: Can benefits be proven on how sequences are established, increasing the KPI capacity, safety, environmental protection?

Trajectory Data Synchronization

- What synchronization level should be achieved to most efficiently handle uncertainty?
- How much uncertainty should be accepted to still grant a robust system behavior?



Thank you!

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