Assessment of the 3D-separation of Air Traffic Flows

D. Gianazza, N. Durand - DSNA-DTI-SDER/LOG

6th USA/Europe ATM 2005 R&D Seminar

June 27, 2005

The general concept of 3D-separation

Network of 3D-airways (tubes) for the main traffic flows

- Geometric separation of the 3D-airways.
- Traffic on the 3D-network
  - should be scheduled by DMAN and AMAN, on each 3D-airway,
  - would have priority over the rest of the traffic,
  - would be removed from the slot allocation process.

- Extension of the *TMA-to-TMA Handover* concept, but in 3D.
- Expected benefits :
  - cumulated delays (see TOSCA WP3) : divided by 3 with 18 % of the traffic on the new network, or by 7 with 32 % traffic ?
  - decrease in the number of conflicts ?

3D-separation in 2 different contexts

France

- 75% international traffic over France
  $\Longrightarrow$ variety of entry and exit levels.
- Entry and exit points issued from standard routes
  $\Longrightarrow$ high concentration of traffic on a few *origin-destination* links (70 links : 40% traffic)

Europe

- 95% intra-european flights,
- *airport-to-airport* links
  $\Longrightarrow$ needs many links to handle a significant amount of traffic (74 links : less than 7% of the traffic)
- star-shaped network.

Underlying problems

Classification

Define 3D-flows, considering entry, cruise, and exit levels.

Optimization

Find optimal *separated* 3D-trajectories for these 3D-flows,

- satisfying *standard separation* constraints,
- as close as possible from the *default trajectories*.

Scheduling

- Departure sequence $\longrightarrow$ no conflict within the same flow,
- Arrival sequence $\longrightarrow$ no conflict over TMA entry points.

This problem is not adressed here.

Algorithms

Classification, considering three models of 3D-flows

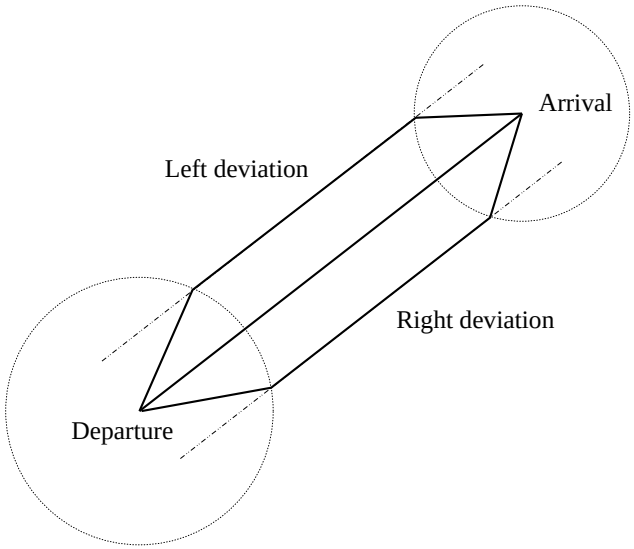
- one trajectory per *origin-destination* link,
- additional trajectories, for flights climbing from, or descending to airports near the border,
- several trajectories per *origin-destination* link $\longrightarrow$ *k-means* partitionning method, applied to entry, cruise, and exit levels.

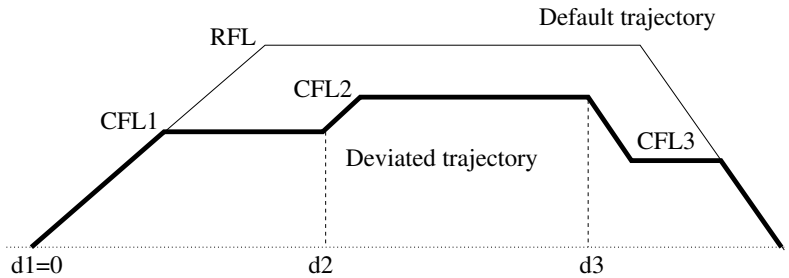
Optimization : 2 strategies

- *1 vs n* : build each trajectory in turn $\longrightarrow$ tree search method ($A*$ algorithm)
- global optimization $\longrightarrow$ stochastic method (evolutionary algorithm).

Basic model

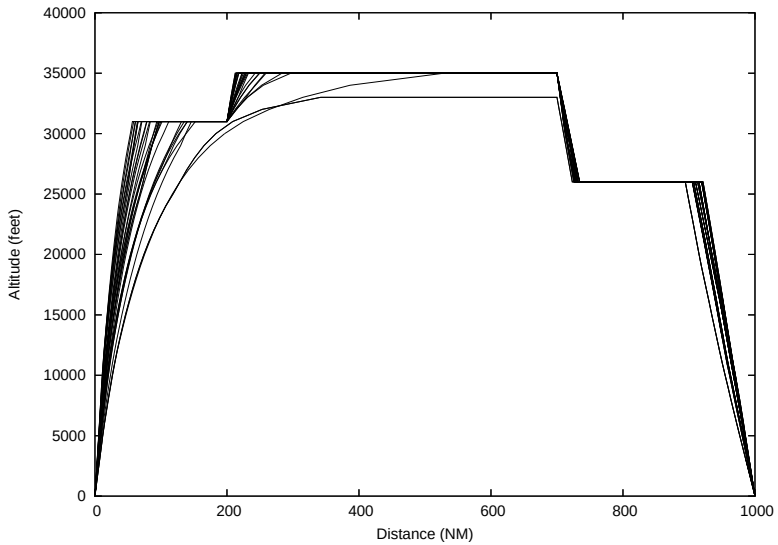
- All airports are at altitude 0
- One trajectory per *origin-destination* link
- Same aircraft performances : linear climb/descent slopes,
- Default trajectory = direct route + cruise at the RFL.
- Lateral and/or vertical deviations :

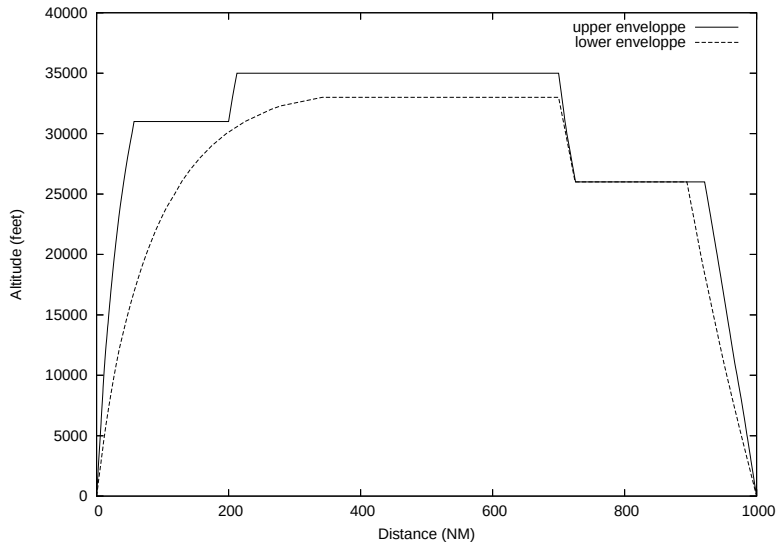




A more realistic model

- Standard routes or direct routes
- Several 3D-flows models (UNIC, PROX, MULTI) with one or several 3D-airways per *origin-destination* link
- Real aircraft performances
- Uncertainty zones





Detection of trajectory interferences

Three detection modes

- Distance between 3D-segments : $\sqrt{\frac{x^2+y^2}{N_h^2} + \frac{z^2}{N_v^2}} < \sqrt{2}$
- Intersection of tubes, defined around 3D-segments
- Intersection of tubes, defined around uncertainty zones

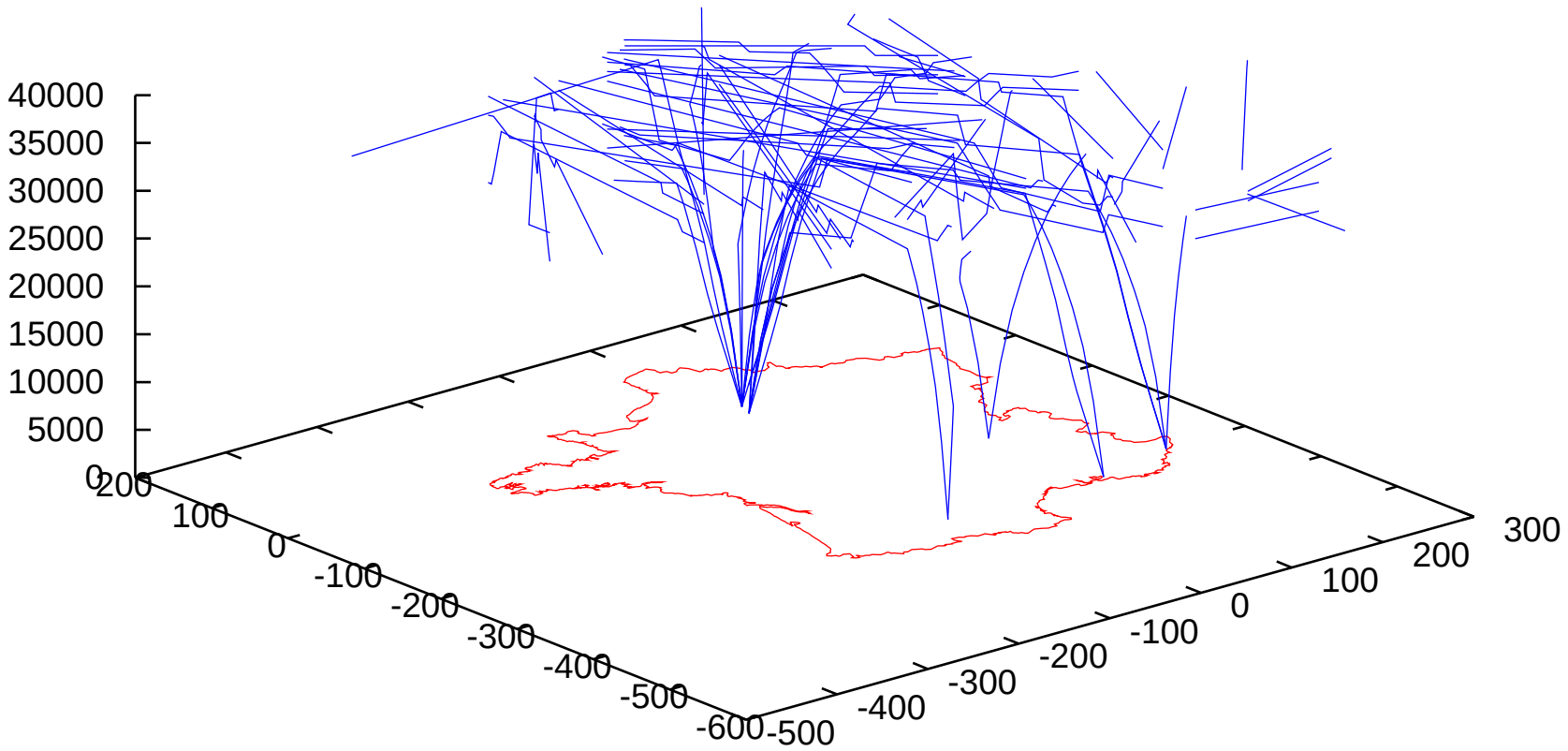
No-detection area

Defined around each airport (15 NM range).

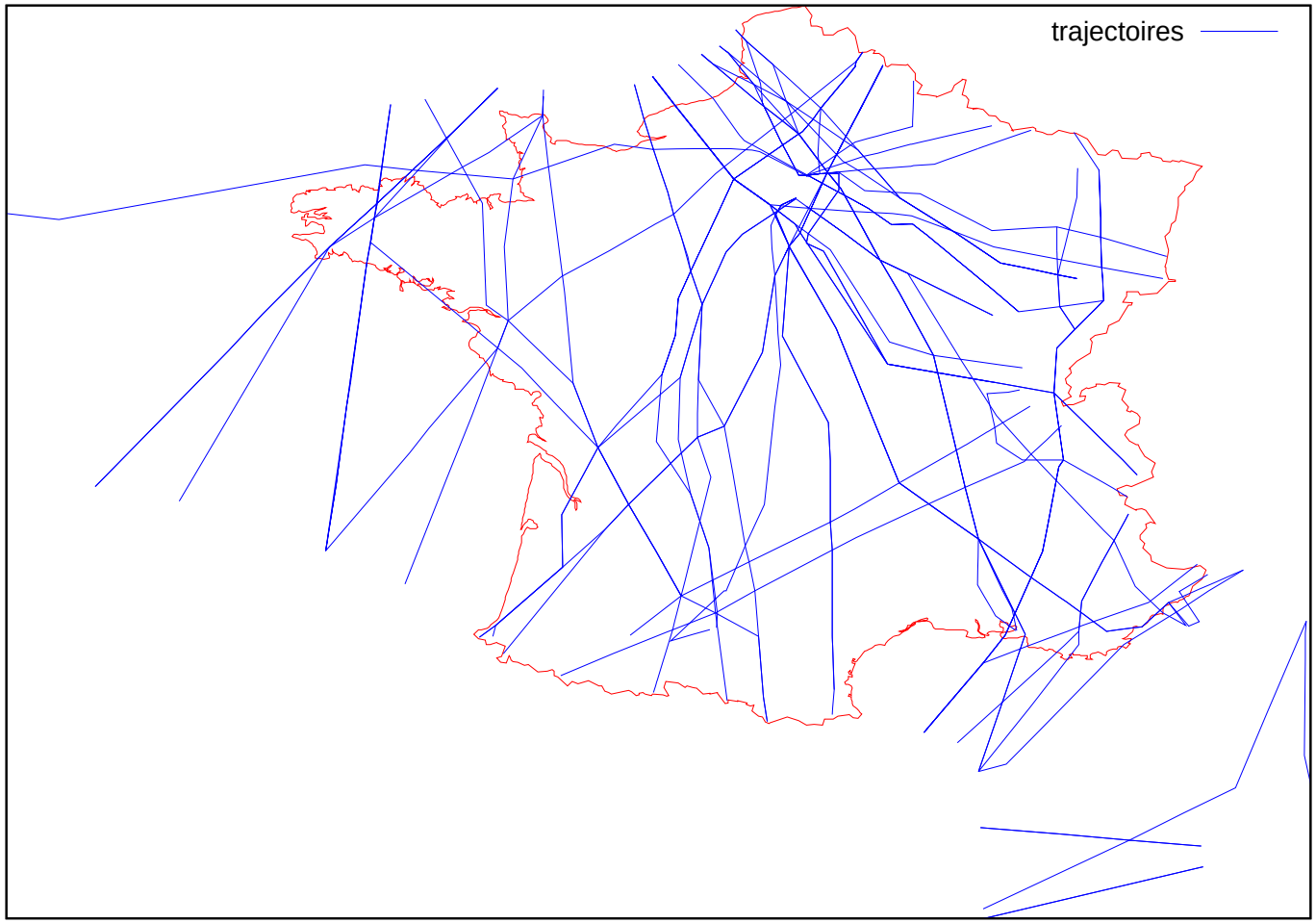
The interference detection is inhibited in specific cases

- for two *initial climbs* from a same airport,
- for two *final descents* towards a same airport.

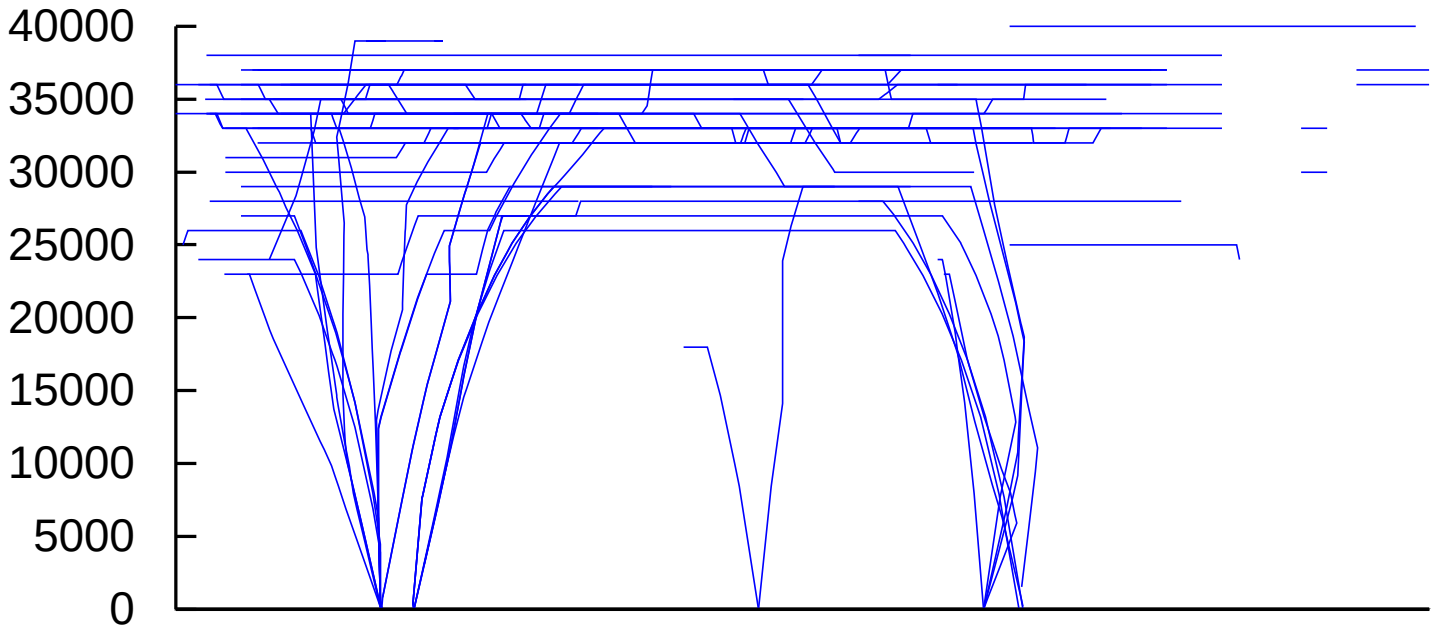
France, direct routes, 71 traj. (1 per O-D, Nb flights per link > 20)



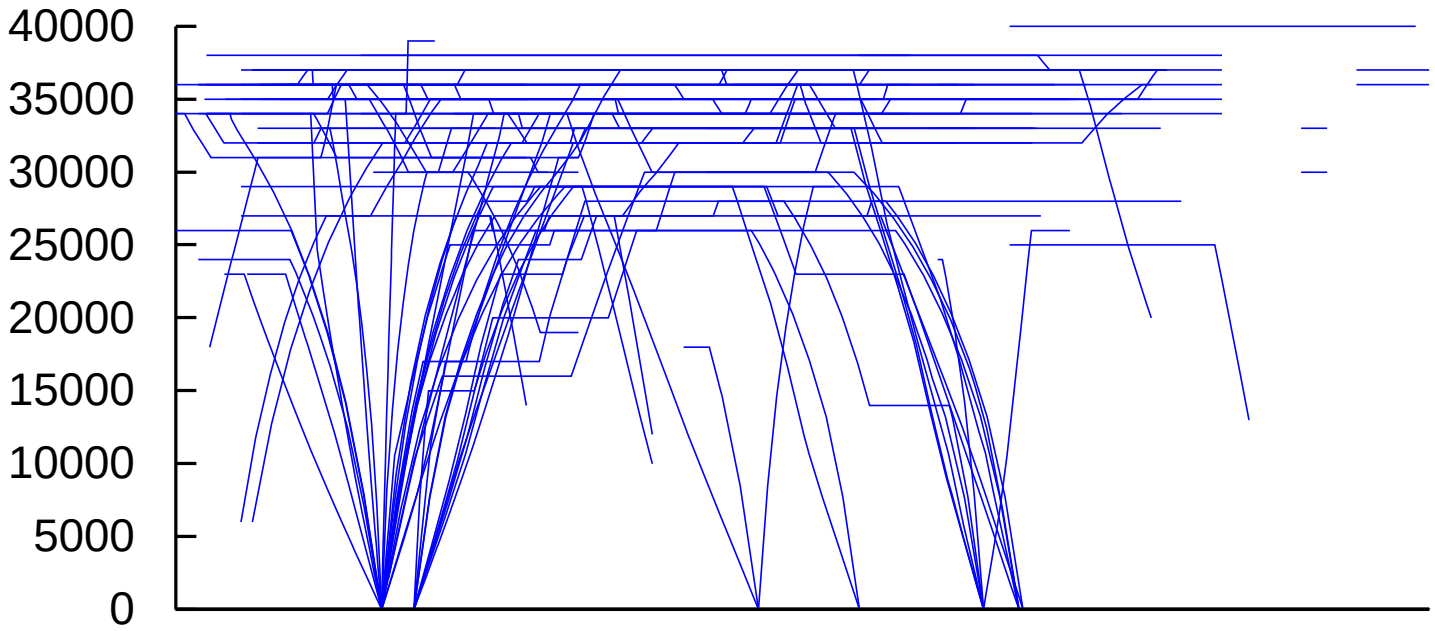
France, standard routes, 72 traj. (1 per O-D)



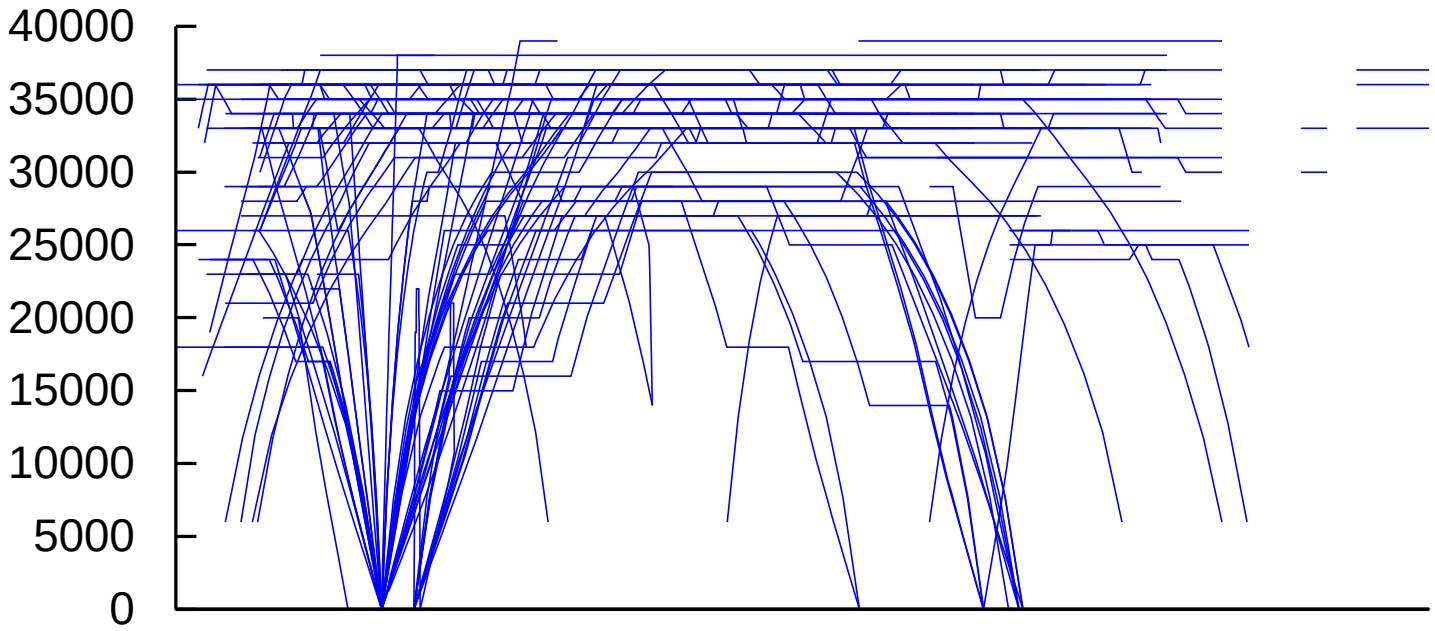
France, standard routes, side view of the 72 traj.



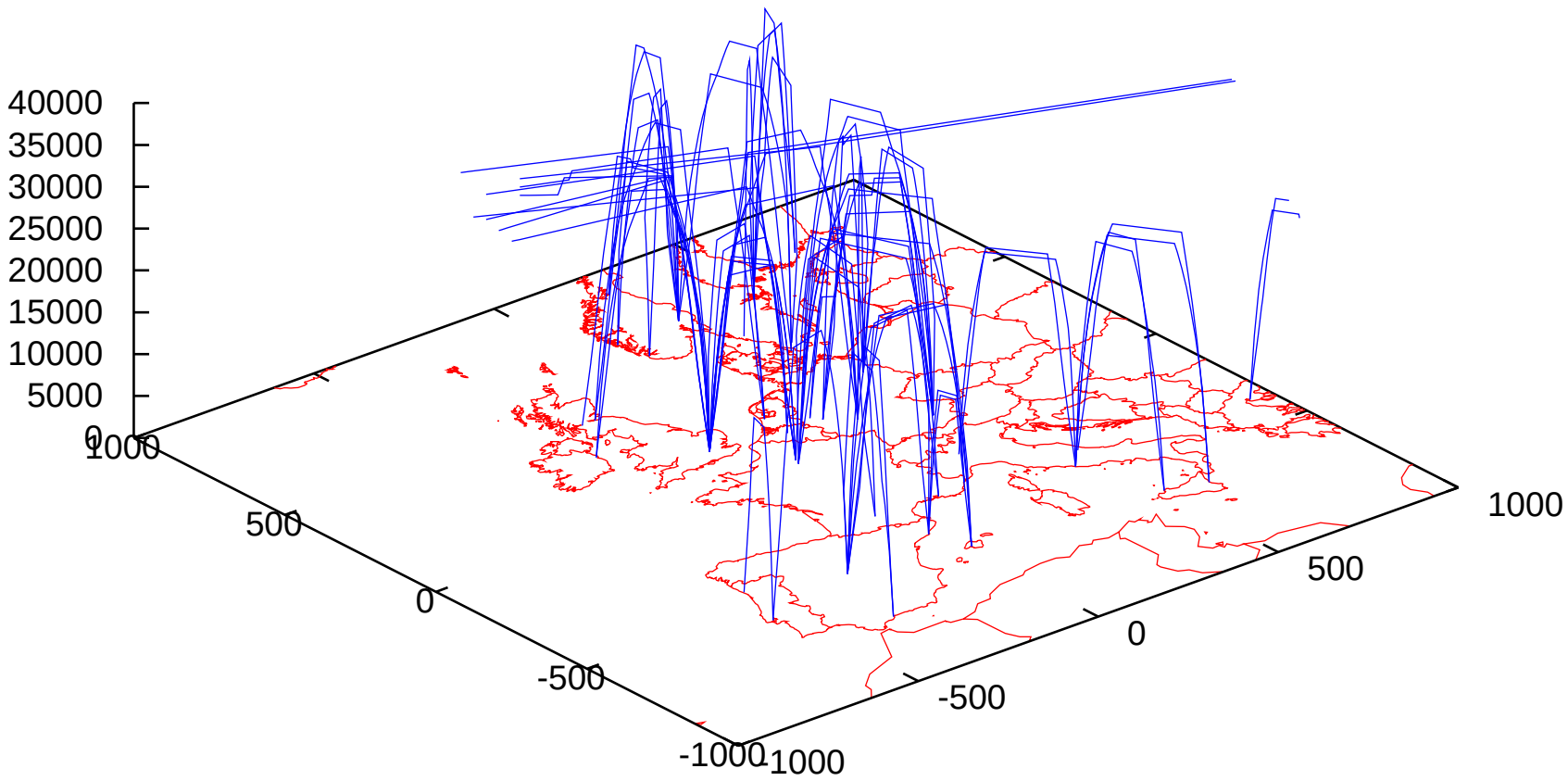
France, 95 traj., airports near border, side view



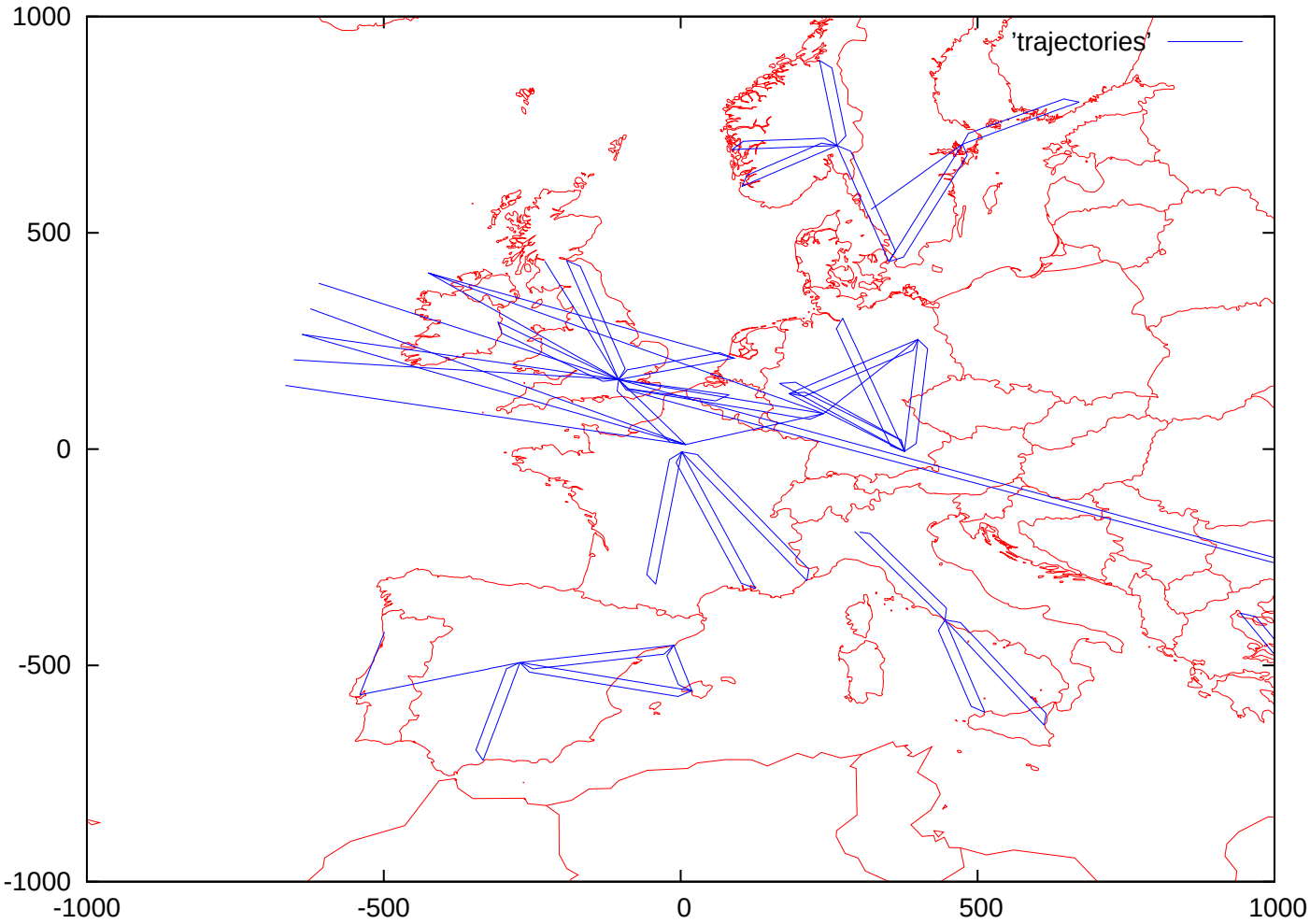
France, 139 traj., several traj. per O-D, side view



Europe, 65 trajectories



Europe, 65 trajectories



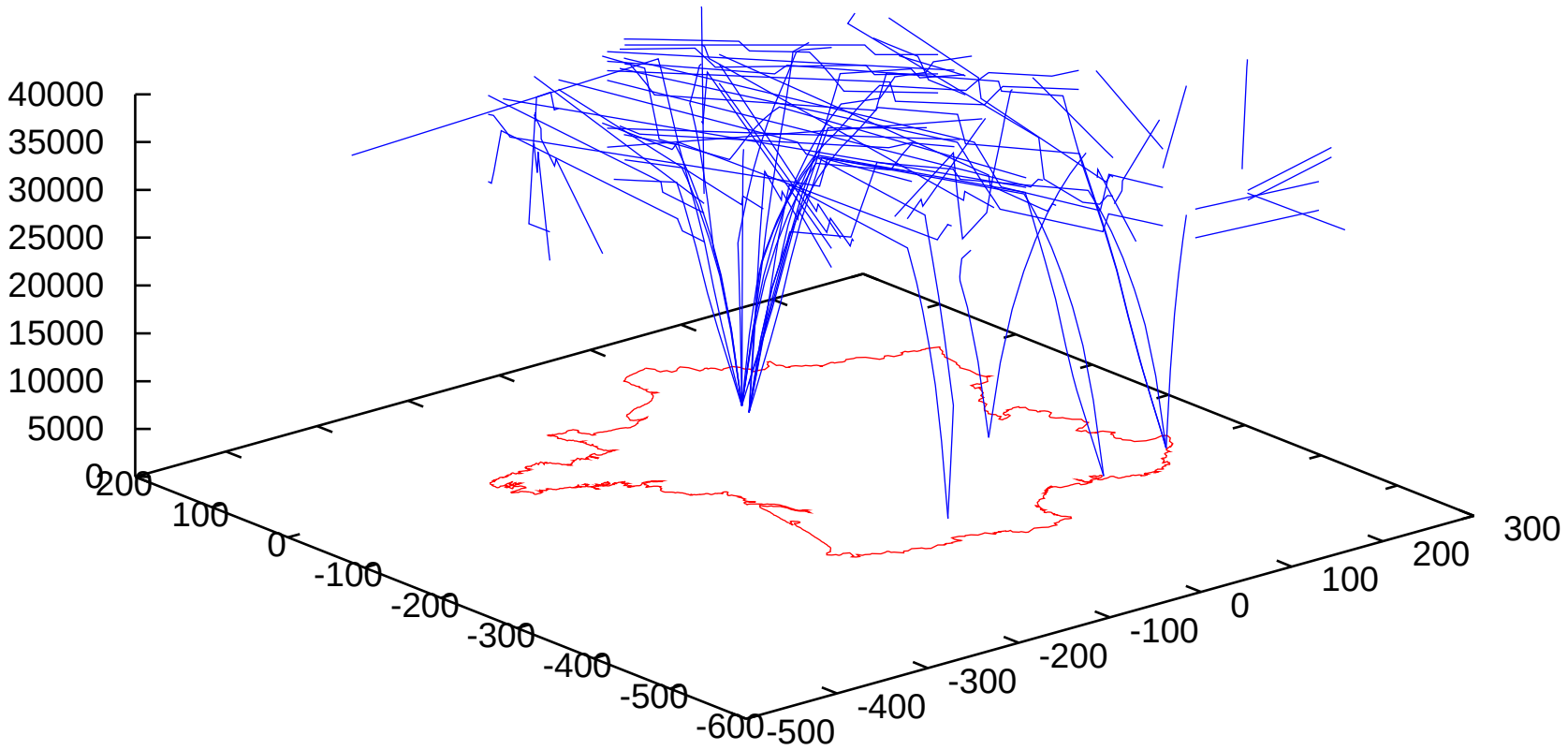
Validation

Objectives :

- make sure that the 3D-separation is effective,
- assess the potential benefits of the 3D-separation concept.

- Fast-time traffic simulations, using CATS/OPAS on one day of traffic (2002, June 21st), over France.
- Assess the number and nature of conflicts.
- Reference traffic *vs* traffic with 3D-network

Effectivenesss of traffic separation



Validation results (A^*, France, direct routes, 71 traj., 1 per O-D)

Detection mode	**DIST-A320**	**ITUBES-A320**	**IZONES**
Nb. fail	0	0	1
Cost	296.64071	260.02877	(205.21511)
Nb. FL $>$ 145	19	19	20
Nb. FL $<$ 145	0	0	1
Route elong.	0.67 %	0.60 %	0.14
p.c. traffic	39.60 %	39.60 %	39.30 %
Above FL145			
Nb. confl. **REF**	1750	1750	2042
Nb. confl. **OPT**	1870	1745	1878
Same flow	329	308	358
Profit	11.94 %	17.89 %	25.56 %
Above FL195			
Nb. confl. **REF**	1389	1389	1582
Nb. confl. **OPT**	1446	1371	1476
Same flow	321	300	342
Profit	19.00 %	22.89 %	28.32 %

Nature of the remaining conflicts

	DIST-A320				
FL>195	Total	Same flow	$\neq$ flows	Mixed	Other
Nb confl.	1446	321	18	543	564
% confl.	100 %	22.2 %	1.2 %	37.6 %	39.0 %

Validation results (A^*, France, standard routes, 72 traj., 1 per O-D)

Detection mode	**DIST-A320**	**ITUBES-A320**	**IZONES**
% traffic	39.04 %	39.04 %	40.02 %
Above FL195			
Nb. confl. **REF**	1389	1389	1582
Nb. confl. **OPT**	1345	1372	1496
Same flow	303	298	357
Profit	25.0 %	22.7 %	28.0 %

Potential benefits (number of conflicts)

- The simulations show a decrease in the number of conflicts, provided DMAN/AMAN schedule the flights within a same flow.
- 3D-separation mainly benefits to upper airspace
- The profit rate is not much related to
  - the chosen method (global or *1 vs. n*),
  - the detection mode,
  - the 3D-flows model.
- It is highly related to the percentage of traffic handled on the 3D-airways.

% traffic	Profit
30%	10 to 15%
40%	20 to 30%
50%	35 to 40%

Concept assessment (over France only)

- Realistic 3D-flows model $\Longrightarrow$ needs more trajectories
  - UNIC (one airway per O-D) : 40 % of the traffic on 70 airways,
  - MULTI (several 3D-airways per O-D) : 30 % of the traffic on 139 airways.
- What may be expected, with the most realistic model ?
  - 30 % of the traffic on a 3D-network of 139 airways,
  - 10 to 15 % less conflicts, *provided the scheduling on airways is made by DMAN/AMAN*,
  - TOSCA WP3 : drastic decrease of the ground delays (divided by 7 ?)
    - if the new network has no incidence on the overall capacity,
    - and if the TOSCA results are still valid in the context of a 3D-network.

Application to Europe ?

- Potential benefits of 3D-separation not assessed.
- We may expect similar results *if a same amount of traffic can be handled on 3D-airways ! !*
- *Airport-to-airport* links = low concentration of traffic.
- We should consider *TMA-to-TMA* links, to expect significant benefits.

Conclusion

Algorithms :

- successfully applied to French and European traffic ;
- current domain of application : 70 à 160 trajectories ;
- Europe (star-shaped network) : algorithms could be parallelized.

Concept assessment (french airspace only) :

- Significant potential benefits ; higher profit in upper airspace.
- Pending issues : scheduling problem, real impact on capacity ?

Check if the congestion/capacity problems are not transferred to the DMAN/AMAN scheduling, or to the airports !