ICAS-88-1.4.1

ATSAM (AIR TRAFFIC SIMULATION ANALYSIS MODEL) A SIMULATION-TOOL TO ANALYZE EN-ROUTE AIR TRAFFIC SCENARIOS

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Abstract

ATSAM (Air Traffic Simulation Analysis Model) is a flexible fast-time simulation-tool, designed to support ATC-related research regarding en-route air traffic scenarios, e.g. to develop new ATC/ATM procedures. The ATSAM model is based on a generalized, somewhat object-oriented modeling of ATS scenario elements/ATM control actions and a detailed continuous aircraft/flight simulation model considering error influences modeled by discrete events. ATSAM allows to assess safety and economy related parameters within en-route ATS scenarios for numerous operational, environmental, traffic-related or aircraft-related boundary conditions. Currently, ATSAM is used to analyze, develop and optimize air traffic flow control and management procedures for the German ATS.

1 Introduction

Due to safety reasons, ATC-related research depends on the availability of flexible simulation-tools to model candidate concepts/procedures and the respective test scenarios with the required level of precision. The software package ATSAM (Air Traffic Simulation Analysis Model), described in this paper, is such a simulation-tool with respect to the analysis of en-route air traffic scenarios.

In contrast to a commonly used network-type approach ATSAM was designed as fast-time simulation with a continuous model to simulate and monitor the dynamic behavior of the different aircraft along their flight paths. Discrete events are used to model ATC commands, system inconsistencies or error influences. Due to the generalized, object-oriented modeling technique and a variety of build-in software features ATSAM supports the modeling of ATS scenarios for almost any set of boundary conditions [2,3]. The developed program package includes pre-processing software to allow the direct input of industry data/data provided by ATC authorities and post-processing software (numerical, graphical) for result data assessment and presention.

The development of the ATSAM was sponsored by the *Deutsche Forschungsgemeinschaft* (DFG). The simulation analysis currently performed is based on the scenario of the Air Traffic System of the Federal Republic of Germany including the adjacent air corridors to Berlin. Simulations are run on a CRAY-X/MP computer, requiring 3.2 MB of core memory.

2 Characteristics of ATSAM

To assess the performance (safety, efficiency,...) of en-route ATC/ATM procedures in a realistic traffic environment a rather detailed modeling of flight movements on a system-wide basis is required, to allow the evaluation of safety-related and economy-related parameters. The application of such a model for research purposes, in addition, implies a number of special program characteristics, e.g. flexibility in modeling, flexible result data output and evaluation features, etc..

The developed software package may be considered as some kind of testbed for en-route ATC/ATM-procedures based on a fast-time simulation of a large en-route ATS scenario. ATSAM models all relevant system elements regarding flight operations (e.g. aircraft dynamics, avionic capabilities, navigation) and considering air traffic control (e.g. surveillance, off-line/on-line control procedures) under conditions close to reality (i.e. various error influences modeled in Monte Carlo technique). In addition to this program package core, pre-processing software to prepare the data input files and on-line/post-processing software to evaluate the achieved simulation result data was written.

Basic design principles in developing the software package were:

- a generalized, object-oriented model/program design,
- a modular layout of the program package,
- an entirely data-/file-oriented scenario definition,
- a data-driven set-up of simulation experiments,
- model/software portability.

The program code developed on the basis of the rather generalized ATSAM model structure may be used for the analysis of a variety of en-route-type ATC-problems without any code modification. In the same way, ATSAM is not limited to a specific ATC scenario/area.

Simulation runs and sample scenarios may be completely defined and controlled by data input. Implemented into ATSAM are the the basic elements/objects required to model the ATS structure/configuration, the traffic demand and environmental influences to define a test scenario, used as testbed for the analysis of ATC/ATM procedures. According to this testbed-function, user-specific ATC/ATM control strategies may be linked to the ATSAM system through special software interface modules. In addition, ATSAM includes knowledge about the relation and the interaction between those different objects, to reject false input data and to add default values for slot-parameters not explicitly specified.

Except for graphics, ATSAM is written in a standard HOL (FORTRAN 77) and thus implementable on almost any other computer fulfilling the requirements of core memory and computing power. Currently, the 'mainframe-ATSAM' is used to develop a numerically reduced model of the program system core, allowing the on-line simulation of en-route air traffic operations within a limited control region on a 16/32-bit microcomputer. The used graphic library is based on the GKS-standard and available for a variety of FORTRAN-compilers on micro-computers, too.

The above given outline of requirements for such a simulation-tool leads to a program architecture with basically four different logical sections of the program system core:

- *the aeronautical data base system* (including basics of aircraft performance/dynamics),
- *the input and generation of traffic samples* (including flight profile planning),
- *the (off-line) ATC/ATM planning process* (i.e. the respective testbed) and
- *the (on-line) ATS-simulation* (including error impact, conditional traffic input, ...).

Figure 1 shows a simplified flow chart of ATSAM, including the pre-processing and the post-processing. Each of the modules/sections shown, represents a software package of its own. In total, the ATSAM program package consists of approx. 20000 lines of code (LOC).

3 Logical Modules/Functional Units of ATSAM

3.1 The ATSAM Direct Access Data Base System

The direct access data base system contains all data needed to describe the entire sample scenario (static/geographic data, performance data, dynamic/flight plan data,...). As ATSAM was developed for research purposes, even otherwise static data may change frequently, e.g. to analyze the impact of modifications of the airspace structure/organisation. Therefore, the first ATSAM program module has to process the the sequential input data files specified by the user into the ATSAM-DBS. According to future ATC/ATM concepts, supporting e.g. the application of fuel-efficient direct routings in an automated control environment, the ATSAM-DBS has to contain more information than a typical aeronautical data base, e.g. with respect to aircraft performance.

3.1.1 The Aeronautical Data Base

The ATS/ATC-scenario modeled by default represents the current ATS/ATC system status. The module processing those data files, however, supports all forseeable system enhancements. By modifying the input data, therefore, the program user may model whatever futuristic scenario he requires. To build-up the entire ATS, ATSAM needs information about:

- navigation systems and locations,
- waypoints,
- entry and exit points,
- airways,
- standard instrument arrival and departure routes and
- standard routes and/or user-preferred routes.

The files containing the information about the geography of the scenario and its configuration are processed in the above cited hierarchical order to allow extended logic checking assuring the consistency of the input data.

All geographic coordinates (of nav-aids, waypoints,...) are transformed by means of a stereographic projection into a cartesian coordinate system. The cartesian coordinate system is used to simulate the movements of the aircraft (with individual speed and altitude profiles) along sequences of waypoints. Typically, such a sequence of waypoints is defined by a routing, combining segments of airways, SIDs and STARs. Simulating area-control concepts, however, routings may be specified as any combination of waypoints.

Navigation systems and techniques are modeled as position errors resulting from inaccuracies of the respective position determination, i.e. ATSAM may be used to analyze the impact of new nav-aids (see [5]). For this purpose, waypoints are not only defined geographically by longitude and latitude but, in addition, a location method using nav-aids is specified. Depending on the available stations, there may be several possibilities for locating waypoints resulting in different position accuracies. Due to historical reasons, most waypoints published in the AIP are defined as overhead waypoints. Besides radio nav-systems (with direction and/or distance information), ATSAM supports the use of satellite information or the use of a generalized nav-system independent definition of position errors. If standard radio navigation systems, e.g. NDB, VOR, DME,..., are used, ATSAM will assign default accuracy values. By specifying the appropriate input data, any nav-system and/or nav-system accuracies may be simulated.

ATSAM uses a waypoint-oriented simulation model. The boundaries of the considered scenario are defined by waypoints, being at the same time the sources and the sinks of the (regular) traffic load. Though, the simulation of flights ends at those waypoints, flight planning and profile optimization is done for the entire flight segment to achieve sufficient realism. If traffic is simulated in a network-type structure (airways, SIDs/STARs) these points are either airports or so-called entry/exit-points (ordinary waypoints with that special property of being a 'boundary-waypoint'). In a direct-route-environment additional waypoints for ATC-coordination purposes have to be defined which may be considered as conventional entry/exit points (for modeling purposes).

Backbone of the current ATS network structure are airways connecting waypoints within the lower or the upper airspace. The airports are linked with this airway system by standard instrument departure and arrival routes (SIDs, STARs). As the ATSAM model emphasizes on en-route traffic operations radar vectoring techniques applied in terminal areas are neglected, i.e. aircraft depart along SIDs and approach the airport along a STAR.

The AIP contains so-called standard routes defining routings between entry points and exit points. In general, there exist several route definitions for each connection. Typically, an analysis will begin using the defined standard routes and/or user-preferred routes. However, the ATSAM model is independent of the current standard route system, allowing e.g. to analyze the impact of a general application of direct routes. To support simulations of area control concepts, the (static) information contained in the aeronautical data base is completed by information about the organisation/sectorization of the airspace and restricted areas. The respective airspace elements are quantified on the basis of a two-/three-dimensional grid-structure.

In addition, a graphics package is available to plot a variety of charts of the modeled ATS scenario. As example, *Figure 2* shows the airway system of the lower airspace around Frankfurt/FRG including the major nav-aids.

3.1.2 Aircraft Performance Data Base

To handle air traffic operations the ATC-module has to have complete knowledge of the ATC-system and a basic knowledge about aircraft performance/dynamics. Considering the anticipated flight profile modifications by ATC, additional performance data are required, compared to currently operating ATC systems. Therefore, ATSAM uses a performance data base which may be specified according to the level of detail needed to perform a specific research task. If no data is available for a particular aircraft type, the system will base its calculations on default values. The aircraft performance data base is used for ATC purposes and to plan/optimize flight profiles, if the simplified flight planning mode is used which seems to be sufficient for most ATSAM applications.

3.2 Traffic Data Input/Generation

3.2.1 Modeling of Traffic Samples

Depending on the given research task, it may either be desirable to use a typical traffic sample or to simulate a specific non-typical traffic situation. To allow a flexible modeling of any required sample, ATSAM offers three different ways to specify traffic demand:

- fixed traffic samples,
- generated traffic and
- conditional traffic.

Fixed samples are used either to work with real data or to analyze specific traffic situations of particular interest. Using the available pre-processing software, actual flight progress strip data may be used to process input flight plan lists containing the basic information about flights from one point of the scenario to another.

Table 1 shows some example data records of a flight plan data input file. The given information includes e.g. when (slot) and where the flight first occurs, the flight number, the days of operation (in *Table 1*, the sample is based on flight progress strip data for a particular Friday in 1985), the departure airport/time, the destination airport/time, the aircraft type, the times and the duration of the flight within the airspace and the entry/exit points if one or both of the airports are outside the simulated area.

However, a dynamic simulation of flights in a future ATC-environment requires additional information, e.g. aircraft payload, level of avionic equipment, etc.. Missing parameters are automatically generated/determined by ATSAM.

The generation of traffic demand is based on a statistical description of a (typical) traffic structure within the simulated area. The generated flight plan list is comparable to the fixed traffic sample input. As the generation process uses a pseudo-random generator, the generated traffic is reproducable as long as the input data remain unchanged. The comparability of the generated traffic with a (typical) real sample depends on the quality of the used data base for generation and on the computing effort regarding the applied data logic checking (e.g. aircraft range check, payload check, fleet check, ...).

The entry times of the flights are coordinated using a user-specified coordination strategy (interarrival times/distances). In case of a combined sample, the generated traffic is integrated into the fixed flight plan list. Typically, the fixed sample describes the basic (current) traffic load and additional traffic is generated to model a future increase in traffic volume.

Flights of the conditional input device with time or situation dependent conditions for initialization are passed directly to the simulation process without coordination to generate defined overload situations.

3.2.2 Route Selection and Flight Planning

For each flight a routing will be selected according to the routes specified in the aeronautical data base. In general, there are several routings available. The selection is based on the length of the flight and the aircraft type. Direct routes may be specified by input data or implemented as a general ATM-strategy.

The most economic altitude and speed profile on the selected route is determined in a way to minimize fuel consumption considering the performance of the respective aircraft type. Though, only a part of the flight may be within the modeled airspace, flights are planned for the entire routing to determine correct profile parameters. Depending on the available data and the required level of precision, ATSAM offers two different profile planning modes: a somewhat 'common sense logic' using the basic performance data available to the ATC and a program package comparable to real flight operations, using an algorithm based on integrated range tables. For most ATSAM applications, however, the simplified flight planning mode seems to be sufficient.

Table 2 shows an example of a speed/altitude profile optimized for a flight from Berlin to Cologne. In this case, however, the desired optimum altitude profile will have to be restricted within the Berlin air corridor. If restrictions apply, ATSAM offers a feature to determine the resulting fuel penalty.

3.3 Simulation of Flight Operations

The ATSAM aircraft model is based on (user-specified) aircraft performance classes. Current array specifications allow to use ten (or less) main performance classes with up to ten subclasses, each. In an object-oriented approach the different classes/subclasses represent an aircraft-type data structure. If the respective input data file does not contain data for a specific slot of a subclass, default values based on the main performance class are assigned.

Flights are simulated using a dynamic model to allow the required level of detail in considering error influences. *Figure 3* shows the general, hierarchical concept of this aircraft/flight simulation model, integrated into the overall ATSAM/ATC system process.

The *off-line ATC/ATM planning* is the outermost level. Result of this planning process are coordinated, conflict-free flight plans. These coordinated flight plans, however, may be modified by interventions of the *on-line ATS simulation*, i.e. by the ATC. On the basis of the flight plan/profile information the *flight management system* (FMS) determines the corresponding profile parameters considering the weather forecast. To be able to consider the impact of various error sources, the FMS determines the correct profile parameters and, at the same time, the deviation due to occuring errors, if error conditions are to be considered for the particular analysis. The model then commands the perturbed values. *Figure 4* shows, as example, the resulting 3D-histogram using this technique to model the impact of the nav-system accuracy (ρ/θ-system, see [1,2]). The *flight path control* algorithm leads the (dynamic) aircraft along the desired trajectories.

The *aircraft dynamics* are represented by a simplified dynamic model with three control parameters (air speed, path angle, bank angle). Compared with results based on the complete set of differential equations of motion, the achieved accuracy of modeling the dynamic aircraft motion through the air space is sufficient with respect to the given research task [1]. In addition, the user may select his own required level of precision by choosing the simulation/integration method (simple Euler-Cauchy or 4th-order Runge-Kutta) and the appropriate time step within the limits given by the model dynamics. During the simulation, actual weather data as specified by the user's wind/weather-model are considered which, of course, may deviate from the forecast used for planning purposes. For each integration cycle the individual aircraft 'send' their actual aircraft state and their position to the modeled ATC. These data may be recorded on tape, e.g. to process plots of the traffic situation.

So far (ATSAM [release 1.0]), the algorithms to simulate flight operations used by the 'off-line module' and the 'on-line module' are basically the same, except for the consideration of error influences and conditional traffic. The 'off-line module' predicts traffic entirely based on flight plan data, beginning with the actual air space situation. The 'on-line module' simulates actual traffic operations including the error impact of various sources. New flights are initialized according to the flight plans/profiles coordinated by the planning function. Numerically reduced prediction algorithms are currently under development.

3.4 Modeling of ATC/ATM Commands

As mentioned above, basically the same algorithms are used by the *off-line ATC/ATM-planning* module and by the *on-line ATS simulation* module. Therefore, the process of monitoring and intervening into the traffic flow, if required, is similar, too. The major difference is just the available time frame to develop a solution (as the planning module predicts traffic some 20 or 30 minutes ahead) and the respective intervention/control strategy, i.e. how to react in a given situation.

In general, the modeling of ATC/ATM commands is a three step process:

> STEP 1:
> First of all, the automatic monitoring detects (potentially) critical situations and checks for the available time frame.

Critical situations may be aircraft/aircraft conflicts (interfering trajectories) or aircraft/airspace conflicts (violations of capacity limitations/restrictions). Time frames of the 'on-line module' are: short-term actual danger, potential danger and bottle-neck situation. The 'off-line module' differentiates between planned conflicts and predicted bottle-neck situations. ATSAM sets the appropriate alert flags and does the required bookkeeping.

ATSAM was basically designed as a testbed to assess the performance of ATC/ATM procedures. ATSAM, therefore, only includes elementary control commands (heading change/command, altitude change/command, speed change/command, rerouting by dropping and/or adding waypoints). Complex control command sequences may be defined using these basic ATC commands. For this purpose, the program user has to specify the control concept/strategy which should be applied, i.e. which should be analyzed by using ATSAM. The specification of a control strategy consists of a table of different traffic situations and related criterias to apply certain command sequences using the available elementary control commands. ATSAM offers special software interfaces to integrate these user-specified control strategies. To give an example: to develop (first-order) ATM-procedures the respective ATM-strategy may be included in the 'off-line module' and the 'on-line module' is used just to monitor the effects of the planning process without intervening into the traffic flow.

> STEP 2:
> To develop a solution if a critical situation has been detected the type of airspace situation has to be identified. According to the user-specified control concept, a 'locally' feasible/efficient solution will be developed.

> STEP 3:
> Depending on the available time frame, the chosen control commands will be immediately executed (i.e. sent to the aircraft) or the solution will be checked for 'global' efficiency. In case of a non-acceptable result the search for a new, more efficient solution is initiated, if the lead time still allows a re-planning (i.e. loop to STEP 2).

3.5 Switching between On-line and Off-line Operating Modes

The *off-line ATC/ATM planning* functions and the ATC control functions of the *on-line ATS simulation* are in principle parallel processes, as the prediction has to run ahead the actual time in a real-time environment. The CRAY X/MP used to run ATSAM, however, allows only batch programming. As a batch operation does not allow an interactive program execution the parallelism of the on-line/off-line module was simplified into a sequential data processing switching between these two modes.

The time interval used for prediction may be selected by the program user. The actual value is the result of a compromise between the strategic character of ATM-procedures requiring longer times and the desired precision of the prediction, declining as the prediction time interval is increased. Reasonable values for the analysis of traffic within the German airspace are about 30 minutes, i.e. every 30 (simulated) minutes the simulation will be stopped, the planning process will be initiated and performed for the next 30 minutes ahead, then the simulation will be continued, and so on, until the (simulated) time reaches the defined simulation end.

3.6 Result Data Assessment

Due to the complexity of the simulated ATS scenario, usually graphical evaluation techniques are advantageous. Furthermore, graphics play an important role in controlling the extensive input data to define the airspace structure/organisation for input errors which may not be automatically detected. Numerical/analytical evaluation methods are used for statistics or to determine parameters of assessment functions.

The ATSAM graphics package was designed to support the assessment of ATSAM result data and, alternatively, to analyze the respective real traffic data (e.g. flight progress strip data). *Figure 5* shows, as example, a plot of the traffic flows within the (lower and upper) German airspace based on actual flight progress strip data.

Depending on the chosen evaluation method, the respective program modules were realized for on-line or off-line operation. Basic traffic statistics and modules for a basic performance evaluation are on-line features. *Figure 6* gives an example of a typical on-line graphics support: the airspace situation display. This 'radar-type'-display may be plotted at constant time intervals. It is used besides the numerical output to achieve a vivid impression about aircraft movements in the airspace during the simulated flight operations. In addition, all relevant data may be recorded on magnetic tape allowing a further off-line assessment.

4 Summary and Conclusions

To assess ATC/ATM-procedures embedded into a realistic ATS scenario a simulation model is required which allows, at the same time, to analyze safety (e.g. separation assurance, consideration of capacities/restrictions) and economy (e.g. direct routes, efficient flight profiles). ATSAM (Air Traffic Simulation Analysis Model) is such a flexible simulation-tool for en-route air traffic scenario.

Though ATSAM was developed as fast-time simulation, the model and the system features were specifically designed to support ATC-related research in a way, comparable to real-time simulation environments, with a major difference: the analysis is done on a system-wide basis considering several hours of traffic operations within a large area. Numerous software switches allow to set-up and perform simulation experiments for most of the problems occuring within the en-route airspace without any modification of the program code. The results given in [5], for example, were achieve by using ATSAM to analyze the impact of navigation accuracy on safety and capacity. Other typical ATC-related problems where the ATSAM program package may be applied to support the required decision-making process are, e.g.:

- modifications of the ATS structure/organisation,
- traffic-related investigations,
- implementation of new technical equipment or
- development of strategies for an automated ATC/ATM.

The simulation analysis currently performed, is based on the scenario of the Air Traffic System of the Federal Republic of Germany including the adjacent air corridors to Berlin.

5 Abbreviations

AIP	Aeronautical Information Publication
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Scenario
ATSAM	Air Traffic System Analysis Model
DBS	Data Base System
FMS	Flight Management System
GKS	Graphical Kernel System
HOL	High Order-Language
LOC	Line(s) of Code
SID	Standard Instrument Departure Route
STAR	Standard Instrument Arrival Route

References

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[3] A. Hörmann; *ATSAM (Air Traffic Simulation Analysis Model) - A Simulation-Tool to Analyze, Develop and Optimize Automated Air Traffic Management Procedures*; in Odoni/Bielli/Szegö, eds.: *Flow Control of Congested Networks*; Springer Verlag, Heidelberg, November 1987.

[4] A. Hörmann; *Automatisierung des Informationsverarbeitungsprozesses der Verkehrsplanung und -koordination im Streckenbereich*; SFB-Workshop *Innovative Lösungen für die Sicherheit im Luftverkehr*; TU Berlin, April 1987.

[5] A. Hörmann; *Fast-Time Simulation of the Impact of Navigation Accuracy on Safety and Capacity (ATS Scenario Adjacent to Frankfurt TMA)*; working paper, ICAO-FANS Scenario-Subgroup Meeting, Cambridge MA/USA, November 1987.

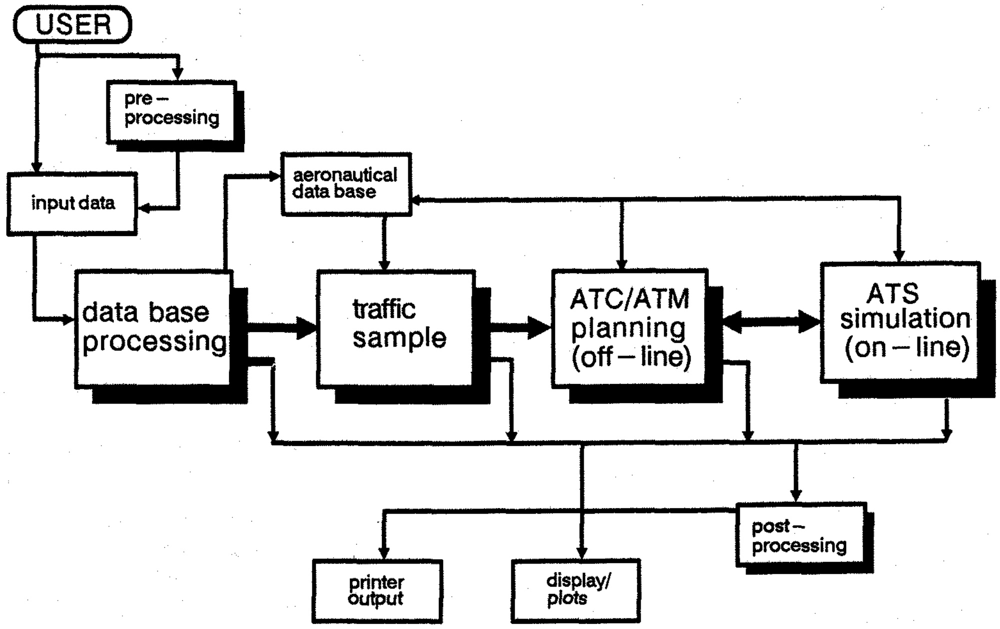

Figure 1: simplified program flow of ATSAM

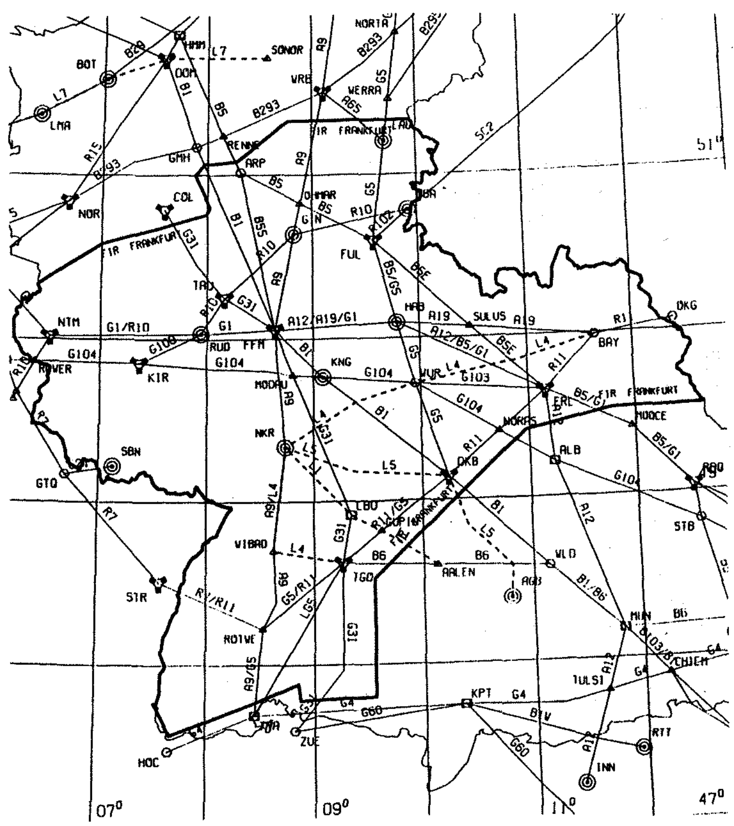

Figure 2: airway-net around Frankfurt/FRG (lower airspace)

SLOT	SECT	FLIGHT	DAYS	DEP	DEST	A/C	TIMES	M	ENT	EXT
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
11001115	FIRD	CY446	0000500	EDDK1100	EDDF1150	EA31	11001150	50		
11001115	FIRD	DEHSD	0000500	EDDK1100	EDWJ1210	C210	11001210	70		
11001115	ELSE	DF459	0000500	LEAL0855	EDDL1117	B727	11001117	17	LNO	
11001115	FIRM	HBVGA	0000500	EDNO1100	LOWW1140	CL60	11001125	25		LNZ
11001115	FIRF	LH112	0000500	EDDF1100	LFPG1155	B727	11001115	15		LUXIE
11001115	FIRF	LH304	0000500	EDDF1100	LIMJ1205	B727	11001120	20		TRA
11001115	FIRF	LH342	0000500	EDDF1100	UUEE1352	EA31	11001123	23		OKG
11001115	FIRF	LH428	0000500	EDDF1100	KATL2015	DC10	11001112	12		DIK
11001115	ELSE	LL519	0000500	LPPT0830	EDDF1109	DC9	11001115	15	LUXIE	
11001115	FIRD	LT1532	0000500	EDDL1100	KJFK1850	L101	11001108	8		LNO
11001115	ELSE	CX200	0000500	EGKK1015	OBBI1600	B747	11011136	35	SPI	NORIN
11001115	ELSE	IB774	0000500	LEMD0855	EKCH1200	DC9	11011124	24	BEDUM	TALSA
11001115	FIRF	AC873	0000500	EDDF1102	CYYZ1840	L101	11021114	12		DIK
11001115	ELSE	AF772	0000500	LFPG1020	EDDH1150	B727	11021136	34	LNO	
11001115	ELSE	JP565	0000500	EBBR1020	LYSP1215	BA11	11021140	38	SPI	NORIN
11001115	ELSE	AC848	0000500	CYEG0336	EDDF1125	L101	11031125	19	ARKON	
11001115	ELSE	BA3125	0000500	EDBT1055	EDDL1145	B737	11031144	41		
11001115	FIRF	OA170	0000500	EDDF1045	LGAT1325	B727	11041139	35		VIW
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.

Table 1: specification of flight plans (example)

BA 315 DEP: EDBT 11:00:00 DST: EDDK 11:42:22

FPL	SEQ	AC	DEP	DST	PLANLW	F-DIST	DIST	NUMWP
1	1	B737	EDBT	EDDK	36000.	260.	260.	11

TIME	WPNAM	X [NM]	Y [NM]	DIST [NM]	FL [-]	TAS [KT]	GW [KG]	F-TIM [SEC]
11:00:00	EDBT	175.22	188.93	0.	0.	250.	38007.	0.
11:00:50	RW	170.47	188.42	5.	25.	250.	37927.	51.
11:02:36	NUVEN	160.58	188.01	15.	78.	250.	37762.	157.
11:09:02	GUSEN	124.67	184.11	51.	269.	337.	37160.	543.
11:15:33	HLZ	84.49	173.38	92.	350.	415.	36740.	934.
11:22:22	NORTA	48.78	142.68	139.	350.	415.	36448.	1342.
11:27:16	WRB	22.93	120.66	173.	350.	415.	36237.	1637.
11:34:03	RENNE	-13.25	104.64	213.	207.	339.	36114.	2044.
11:35:55	GMH	-22.92	100.49	224.	160.	339.	36089.	2155.
11:40:13	WYP	-46.16	93.45	248.	53.	250.	36029.	2413.
11:42:22	EDDK	-51.56	82.58	260.	0.	250.	36000.	2542.

Table 2: flight profile optimization (example)

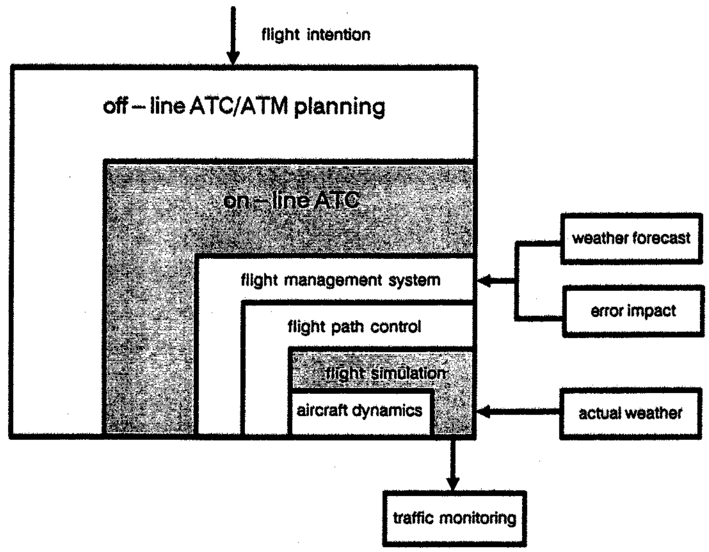

Figure 3: hierarchical concept of the ATSAM flight simulation model

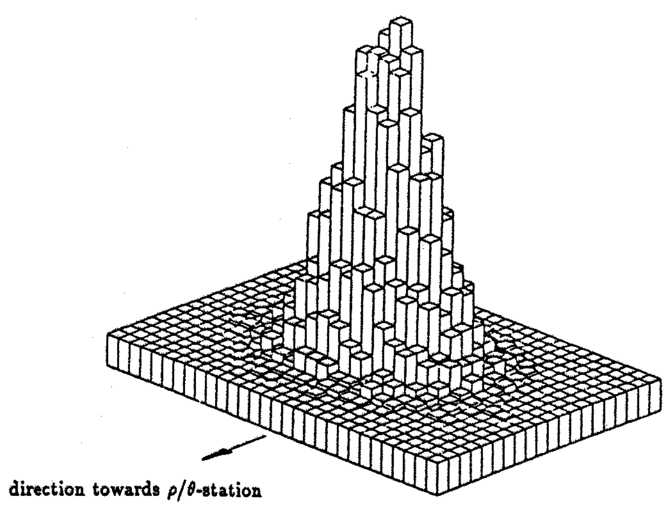

Figure 4: example-histogram of the resulting position error (ρ/θ-navigation)

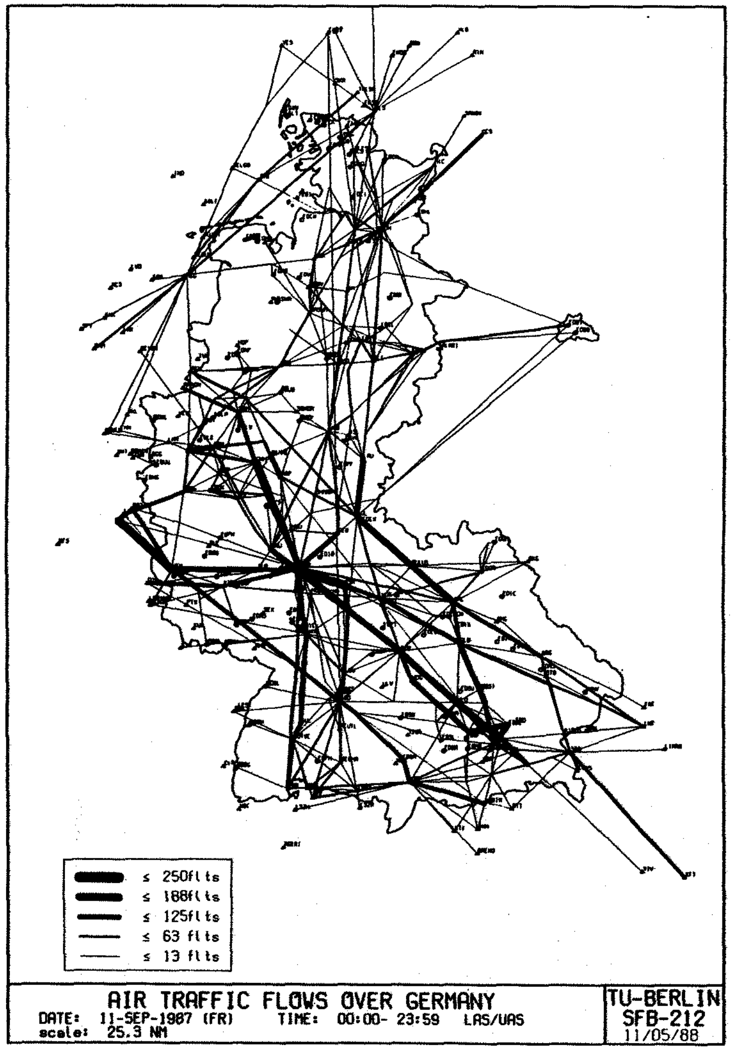

Figure 5: ATSAM graphics: traffic flow chart (example)

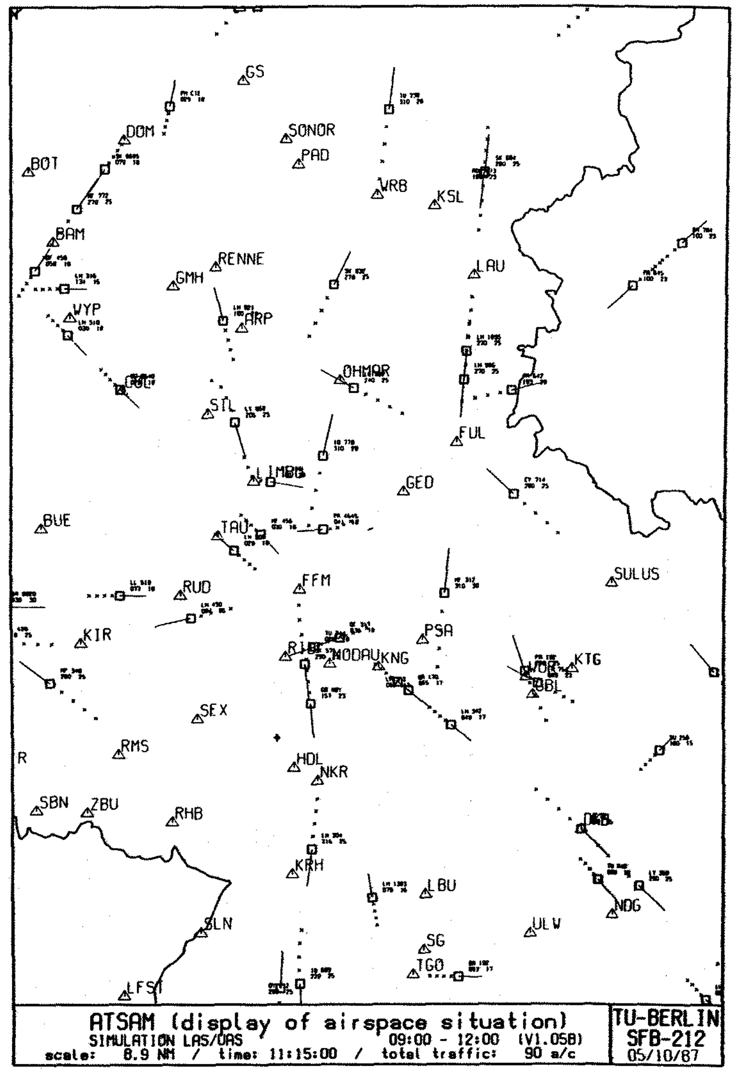

Figure 6: ATSAM graphics: traffic situation display (example)