TECHNOLOGIES AND ADVANCED OPERATIONS TO ENHANCE CAPACITIES THROUGHOUT THE AIR TRANSPORT SYSTEM

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Abstract

To handle the still increasing traffic flows of aircraft, freight and passengers in the future in an economic, efficient and safe manner, is an ongoing challenge of using available technologies and advanced operational concepts as well as using economical and political means to enhance the limited resources like capacities throughout the air transport system. Achieving the goals of the future and guaranteeing mobility and flexibility by aircraft at any time and worldwide means team working of international experts on a global top down approach covering the identified problem areas in an integrated way.

Foreword

While preparing this presentation we had to recognize that our project turned out to be a very ambitious task. Our intention was and is to cover within about 20 minutes the Air Transport System which is without any doubt a very comprehensive and complex system and which is also very dynamic at any times, i.e. it is changing its face in short time intervals. We finally found that we have two options: Either to give a general overlook of the total system (with selected illustrations/examples) or to give detailed descriptions of specific capacity issues. We decided for the first option in the hope for raising more interest in the subject *system capacity* and it will be kept on the agenda for future ICAS events.

Introduction

The Air Transport System/Network is a key contributor to the development of national economies and the growing demand for mobility worldwide. The positive perspectives of the aviation industry, however, might face some limiting aspects because of insufficient capacities of the infrastructure (airports and airspace), environmental constraints and the resulting restricted fluidity of air traffic (Fig. 1)

Where are the main infrastructure bottlenecks? They occur at all points on the flight profile (Fig. 2) - within the *airspace* (en-route, approach and departure phases), on *runways* and *taxiways*, at *gates* and during ground servicing (*turn-around*).

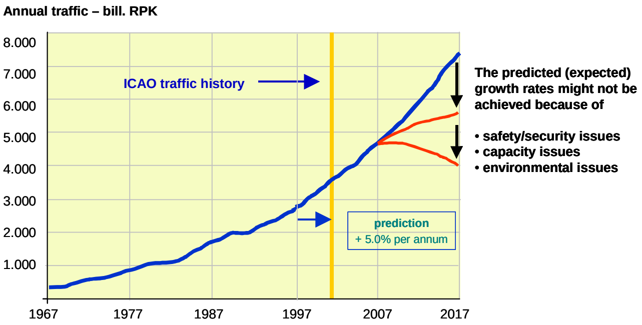


Fig. 1: Predicted (expected) growth of air traffic [1]

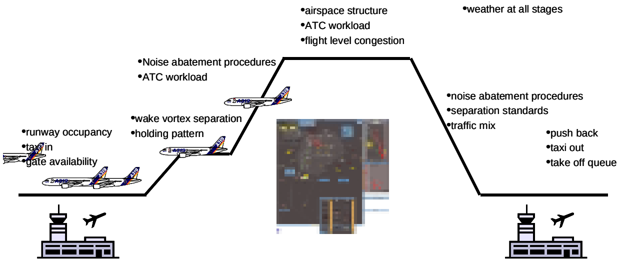


Fig. 2: Capacity constrains from gate to gate [2]

The *total system capacity* must be considered. All bottleneck issues have to be addressed in parallel, otherwise the traffic throughput cannot be sufficiently enhanced. Air traffic has more than doubled over the last two decades. Despite the downturn experienced since September 2001 and due to SARS, air traffic is now recovering again and growth rates of around 4-5 % seem to be achievable again. This will inevitably stress the airport and air traffic management (ATM) infrastructure well beyond its current maximum capacity, especially in its busiest airspace sectors and airports.

Delay rates in Europe and North America are presently still at levels which are unacceptable (Fig. 3, 4)

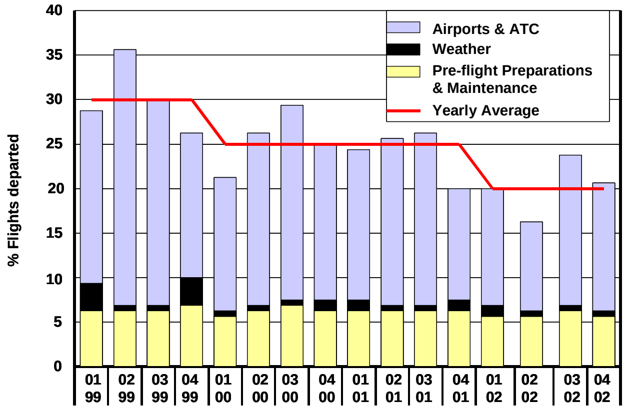


Fig. 3: AEA quarterly delay rates on Intra European services [3]

(% Departures delayed more than 15 minutes *by reason)*

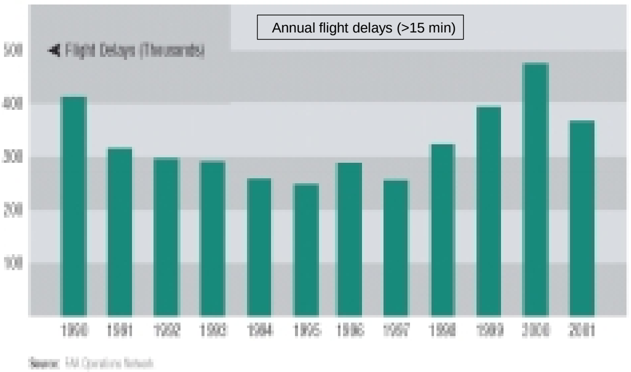


Figure 4: Annual Flight Delays in North America [4]

About 30 European airports are presently capacity constrained. 22 European airports are constrained by issues related to the airport infrastructure (runways and taxiways). 22 European airports are constrained by issues related to the Terminal infrastructure (gates, ------). 19 European airports are constrained by issues related to environmental policies. 14 European airports are constrained by issues directly related to air traffic control and management. Most critical airports in 2001 were Amsterdam, Frankfurt/Main, Milan, Athens, London LHR, Barcelona and Paris CDG.

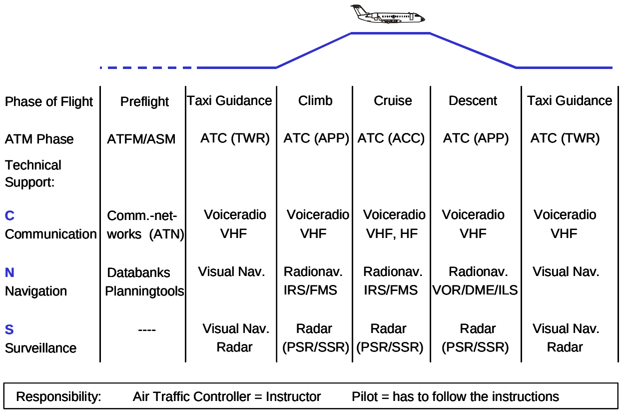
Also about 30 North American airports are capacity constrained. The 10 most critical airports in 2001 were Atlanta, Boston, Newark, Houston, New York JFK, Los Angeles, New York LGA, Chicago, Philadelphia and San Francisco.

It is important to appreciate that the airlines have always incorporated expected amount of delay in their published timetables. The estimated flight times are always 15-20 minutes longer than for a “no delay“ flight.

For example: In the published timetable of Lufthansa German Airlines flights from Hamburg to Frankfurt have flight times from 75 to 85 minutes. If most delays can be avoided, the flight time can be only 55 minutes.

Technologies on board the aeroplane and on ground with potentials to enhance capacities

Some years ago ICAO defined the term CNS/ATM (communication, navigation, surveillance / air traffic management) which describes on one hand the technologies, tools and infrastructure of flight guidance and control and on the other hand the air traffic management which includes the areas of air traffic flow management, air space management and air traffic control. To analyse the key-technologies in view of the potentials for the enhancement of capacities and economic flight profiles we have also to be aware of the today's situation which is shown in Fig. 5.



Phase of Flight	Preflight	Taxi Guidance	Climb	Cruise	Descent	Taxi Guidance
ATM Phase	ATFM/ASM	ATC (TWR)	ATC (APP)	ATC (ACC)	ATC (APP)	ATC (TWR)
Technical Support:						
C Communication	Comm.-net-works (ATN)	Voiceradio VHF	Voiceradio VHF	Voiceradio VHF, HF	Voiceradio VHF	Voiceradio VHF
N Navigation	Databanks Planningtools	Visual Nav.	Radionav. IRS/FMS	Radionav. IRS/FMS	Radionav. VOR/DME/ILS	Visual Nav.
S Surveillance	----	Visual Nav. Radar	Radar (PSR/SSR)	Radar (PSR/SSR)	Radar (PSR/SSR)	Visual Nav. Radar

Responsibility: Air Traffic Controller = Instructor Pilot = has to follow the instructions

Fig. 5: Today's CNS/ATM technologies to support the flight guidance process [5]

The civil and global usage of satellite systems like GPS results into new operational applications of communication, navigation and surveillance in aviation. For communication purposes data links based on SATCOM, VDL or SSR-Mode S are possible. In the area of navigation GPS has opened the door for RNAV- Routings and RNAV areas worldwide. RNAV-routings and RNP-concepts are already operational. The precision-landing-system GBAS (ICAO CAT I) is ready for certification. The new dimension in the area of surveillance can be seen in ADS applications. Air traffic control itself changes rapidly in Europe influenced by the so called "Single Sky Concept".

The decentralized Air Traffic Management Services become more and more centralized. The availability of the CNS technologies support the *ground based - satellite based* flight guidance process. The Air navigation services provide, supported by the potentials of the new technologies, a co-operative spectrum of services (Fig. 6).

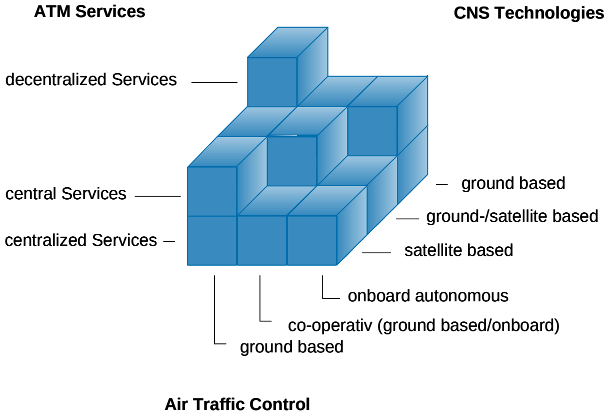


Fig. 6: Air navigation services scenarios [6]

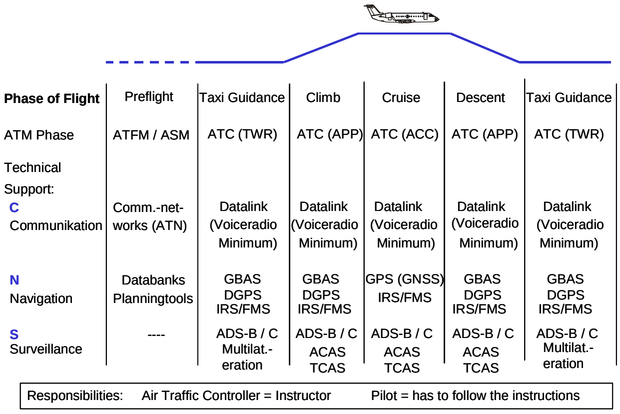
To characterize the nature of air navigation services of the next future it can be said that the:

- Air traffic control is *co-operative* between air traffic controller and pilot
- CNS technologies are *ground based <u>and</u> satellite based* (mixture)
- *central* Air Traffic Flow Management
- *centralized* air traffic control services

The CNS key-technologies can be seen in the area of:

Communication:	Satellite systems (AMSS) Data links (VHF, HF, SSR Mode-S), Global worldwide ground networks (ATN)
Navigation:	GNSS (GPS, GLONASS, GALILEO, GBAS, augmentation services), geostationary satellites
Surveillance:	ADS applications, SSR Mode-S, multilateration concepts

In consideration of all contingencies and assigning the key-technologies to the phases of flight the CNS/ATM scenario of the next future could be seen as follows (Fig.7):



Phase of Flight	Preflight	Taxi Guidance	Climb	Cruise	Descent	Taxi Guidance
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Technical Support:						
C Communikation	Comm.-net-works (ATN)	Datalink (Voiceradio Minimum)	Datalink (Voiceradio Minimum)	Datalink (Voiceradio Minimum)	Datalink (Voiceradio Minimum)	Datalink (Voiceradio Minimum)
N Navigation	Databanks Planningtools	GBAS DGPS IRS/FMS	GBAS DGPS IRS/FMS	GPS (GNSS) IRS/FMS	GBAS DGPS IRS/FMS	GBAS DGPS IRS/FMS
S Surveillance	----	ADS-B / C Multilat.-eration	ADS-B / C ACAS TCAS	ADS-B / C ACAS TCAS	ADS-B / C ACAS TCAS	ADS-B / C Multilat.-eration

Responsibilities: Air Traffic Controller = Instructor Pilot = has to follow the instructions

Figure 7: CNS/ATM technologies to support flight guidance and control in the next future [7]

An overall view of the scenario (existing and advanced technologies included) is shown in Fig. 8.

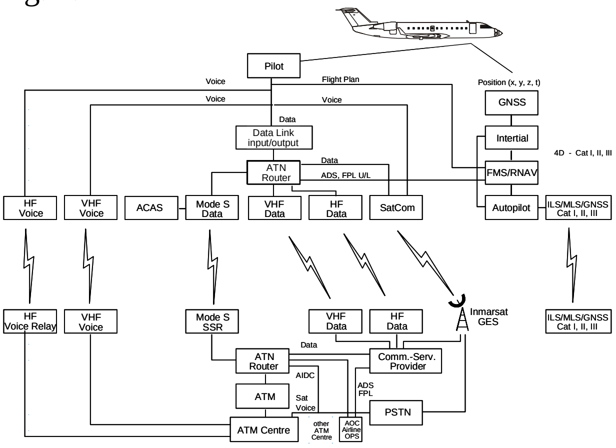

Fig. 8 : Overall CNS/ATM scenario [8]

From the flight operations point of view the mentioned key-technologies open an area of advanced operational opportunities, increasing capacities in the airspace and fulfilling the requirements of economic flight profiles. Based on the support of these technologies operational scenarios like “autonomous flight guidance”, “free flight”, “collaborative decision making” etc. become possible. The advanced operational concepts include more freedom for pilots to be responsible for their own planning and coordination of the trajectories of the aeroplanes from gate to gate.

Even such operational concepts mean the realisation of new or advanced onboard functions like:

Planning functions:	Operational flight planning, part wise conflict free planned trajectories;
Coordination functions:	Coordination “aeroplane to aeroplane” to use the airspace conflict free and efficient;
Control functions:	Responsibility and control of the precise flight on the planned trajectory;

For the operational performance of those scenarios aeroplanes must be equipped at minimum as follows (Fig. 9):

Onboard Function	Technology / Equipment
keep on trajectory	GNSS, RNAV-Equipment, IRS, Autopilot
conflict free coordination “aeroplane to aeroplane”	GNSS, Datalink, ADS-B, ADS-C , ASAS
Conflict prediction, -warning, -solution	A-ACAS
gate to gate navigation	GNSS, A-FMS, RNAV -Equipment
keep on separation	ASAS
Functions on Ground (ATC in TMA)	Technology/ Equipment
Establishing separation minima for take-off and landing aeroplanes	GBAS (D-GNSS), ADS

Figure 9: Onboard functions for aeroplanes and technological tools / equipment [9]

Ground operations and ground handling

The efficiency of ground operations on runways, taxiways and on the apron as far as the overall ground handling are determining mostly the turn-around times the of the aeroplanes. The bottlenecks and operational requirements are briefly listed:

Ground operations

Bottleneck: Runway acceptance rate due to large differences in runway occupancy times, loss of slots or because minimum separation criteria cannot be applied by air traffic control.
Requirements: Reduce runway occupancy times to less than 40 seconds by introduction of an automatic taxi guidance system and high utilisation of high speed runway exits.
Bottleneck: Congested taxiways because of slow and different taxi speeds, queues at intersections and stop bars and complex traffic guidance.
Requirements: Introduction of an automatic taxi guidance system and, in addition, airport traffic display in the cockpit.
Bottleneck: Restricted utilisation of manoeuvring areas due to incompatible aeroplane parameters, e.g., wingspan, wheel base, wheel track, length, height, aircraft classification number (ACN).
Requirements: Create conditions to reduce prescribed safety distances by a more precise automatic taxi guidance system, which guarantees a maximum deviation from taxiway centrelines of 0.5 m and allows at the same time more flexible taxi procedures such as guided oversteering and rerouting (in case of construction work) by creating appropriate virtual taxi centrelines presenting these to the pilot.

Fig. 10 and 11 show the design requirements for ICAO Code F airports and the potential reduction of safety distances if reliable taxi guidance systems could be used.

Bottleneck: Gate availability.
Requirements: Reduce turn-around times by streamlining the complete ground servicing process. Introduction of Collaborative Decision Making with a turnaround monitoring and management system.

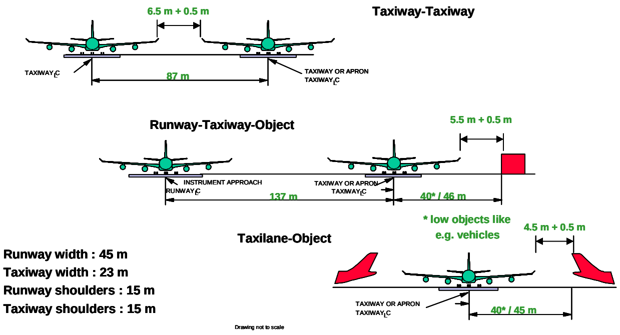

Fig. 10: ICAO requirements for airport Code F [10]

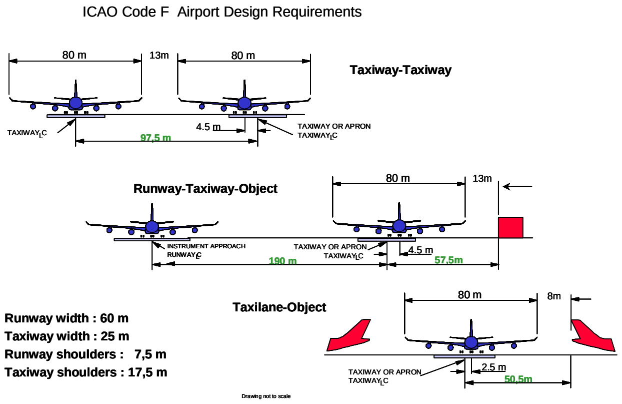

Fig. 11: Potential Operational Standards (taxi deviation max. 0.5 m) [11]

Ground handling

Improved technologies and advanced ground handling procedures are necessary to reduce turn-around times, increase gate capacity and improve gate management.

As already mentioned before, bottlenecks occur not only during the operational phases when an aeroplane is moving or flying, insufficient capacity can be also observed at ground handling positions or terminal gates and the overall throughput is negatively impacted.

A general goal must be the reduction of turn-around times. Two "dimensions" have therefore to be considered in this area: The ground servicing around an aeroplane (Fig. 12) and the procedures in the cabin (Fig. 13)

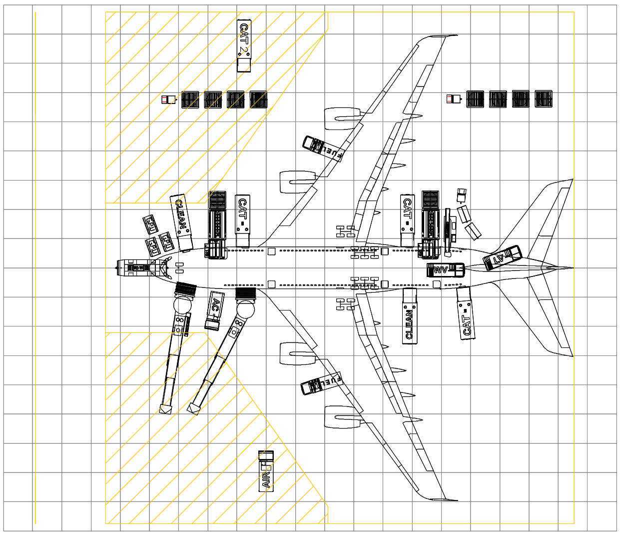

Fig. 12: Ground servicing around an aeroplane [12]

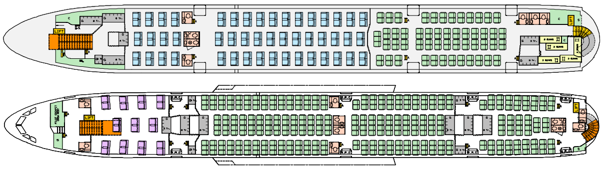

Figure 13: Cabin layout of an aeroplane [13]

When analyzing all processes of a turn-around (Fig. 14) the critical path in this specific example is the positioning and retracting of the passenger bridges the disembarking and embarking of passengers and refueling.

Three ways to reduce turn-around times can be followed:

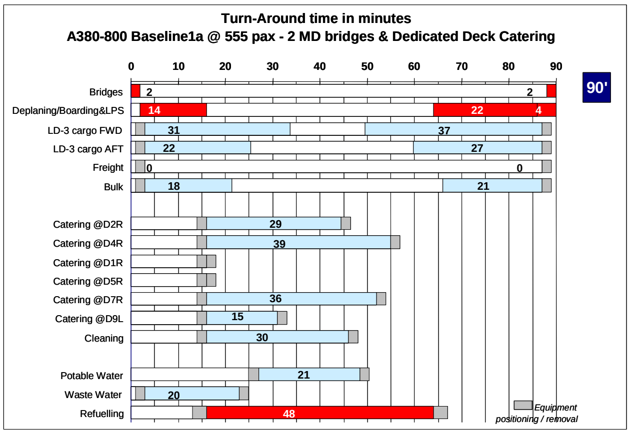

Fig. 14: Turn-around time of an Airbus 380-800 [14]

Arrange for more parallel activities, avoid unnecessary sequencing of single events, e.g. refueling while passengers are still or already in the cabin.

Optimize and shorten single events:

<u>Boarding</u>; Improved guiding of passengers by better (standardized) marking of seat rows and seats, printing of cabin layout with seat assigned on the boarding pass, colour markings of different cabin zones, better accessibility and larger hat racks, folding aisle seats to provide for larger aisle width, wider cabin doors, utilization of rear doors.

<u>Cleaning:</u> Automatic cleaning of lavatories and galleys, garbage container per seat / seat row, "cleaning friendly" materials for seats, floor, walls etc., specific cleaning items to be performed during flight, folding seats for better accessibility.

<u>Catering:</u> Loading and unloading of trolleys via lower / cargo deck (lift system required), abandonment of catering on short-haul flights (< 1 hrs), separation of galleys from passenger flow to allow parallel catering, hand-out of duty-free articles after disembarkation.

<u>Fuelling:</u> Higher flow rates, larger number of fuel connexions.

Positioning of service vehicles: Precision guidance systems for passenger bridges and service vehicles.

Gate management: Reliable and frequently updated information about the status of ground service for every aircraft together with an accurate estimate when ready to leave the gate / parking position

In-flight operations

Bottleneck: Runway occupation: Limitations in case of single runway operation with mixture of arrivals and departures or parallel runways with insufficient spacing to allow independent operations; large differences in runway occupancy times, depending on pilots skills, operator's regulations and weather conditions.
Requirements: Improve bad weather operations by technical means; reduce runway occupancy times by automatic standardised take-off procedures; suitable information from control tower on readiness for immediate take-off; improve navigation accuracy to guarantee no deviation from prescribed flight path even in adverse weather (crosswind) conditions.
Bottleneck: Wake vortex: Regulatory wake vortex aircraft separation minima limit the theoretical runway throughput.
Requirements: Establish advanced wake vortex theoretical and detection methods and convince appropriate authorities to alter wake vortex regulations, when suitably developed, in view of a reduction of wake vortex separation minima, on the aircraft: reduce vortex strength (of the leading aircraft) and/or enable aircraft in trail to encounter vortices safely with additional functions of flight control and high lift devices. Install the ability to avoid encountering any wake vortex by suitable onboard detection and indication systems.

Separation rules and practise:

- currently based on take-off weight only
- critical case is the landing phase (95 % of incidents)
- Vortex strength also depends on span and aerodynamic properties (not taken into account for classification)
- Differences between ICAO, FAA and CAA (Weight categories and separations)

Vortex separations limit capacity of various major airports:

- Worldwide efforts to reduce separations to improve airport productivity;
- Vortex detection and warning systems to be developed;
- Desire to rationalize separation rules;

Bottleneck: Arrival path. Congestion on the arrival flight path can only be avoided if all aircraft use the same Standard Arrival Routes (STARs).
Requirements: Enable the use of optimised noise abatement procedures as a standard.
Bottleneck: Low visibility conditions lead to higher runway occupancy times after landing and subsequent increased arrival separation criteria.
Requirements: Reduce runway occupancy times by introduction of an automatic taxi guidance system (see 'ground operations').
Bottleneck: Cruise phase. Air traffic control controls sectors/units workload limitations due to congested voice communication channels.
Requirements: Reduce workload in the cockpit and on the ground by applying data links and automated flight profile negotiations between ground and airborne systems.
Bottleneck: Air traffic control separation standards.
Requirements: Minimum safety distances can only be applied when aeroplanes are flying at same speeds. Design aircraft with a larger bandwidth of optimum cruising speeds, i.e., minimise fuel consumption penalties when flying off ideal optimum cruise speed.
Bottleneck: Congestion at cruising levels.
Requirements: Larger bandwidth of optimum cruising levels, i.e., minimise fuel consumption penalties when flying off ideal optimum alti-

tude. This aspect is also particularly beneficial for all aspects related to global warming.

Ways to avoid environmental restrictions:

For the further development of the air transportation system the fast growing environmental restrictions have a very negative impact on capacity. Aeroplane noise is still the most important factor and causes capacity limitations worldwide. Restrictions due to emission regulations are gaining more and more importance.

Research programs carried out by research institutes and also by the aviation industry itself are dealing with noise reduction are mainly concentrated in two areas:

- Noise reduction at the sources of noise, i.e. at engines and airframe (Fig. 15);
- Noise reduction through implementation of advanced noise abatement flight procedures (Fig. 16, 17).

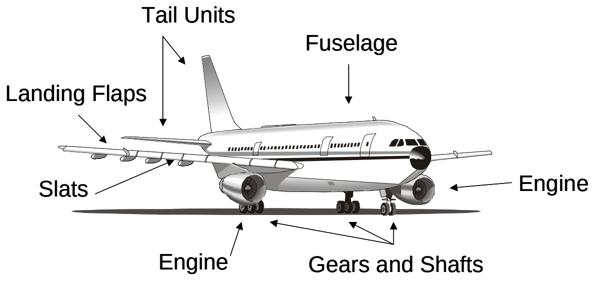

Figure 15: Aeroplane sources of noise [15]

In recent years different take-off procedures have been studied and or are in use to reduce noise over populated areas near airports. Because each airline may base its choice for a procedure on special requirements.

In ICAO’s PANS-OPS, part V, chapter 3 two take-off climb procedures (A and B) are recommended. These aeroplane operating procedures have been developed to ensure that the necessary safety of flight operations is maintained whilst minimizing exposure to noise on the ground. One of the two procedures should be applied routinely for all take-offs. Trials have shown that procedure A results in noise relief during the latter part of the procedure whereas procedure B provides a noise relief during that part of the procedure close to the airport . The procedure selected for use will depend on the noise distribution required and the type of aeroplane involved. The flight profiles of the procedures are shown in figures 16 and 17.

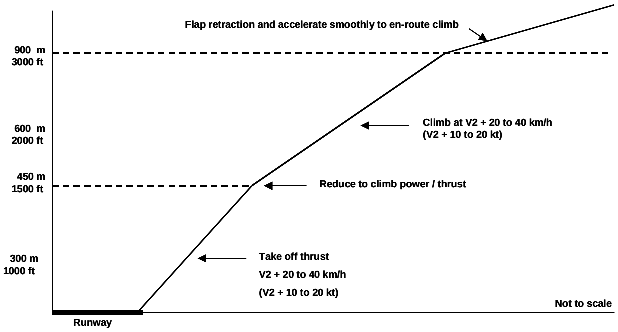

Figure 16: Noise abatement take-off climb - Procedure A [16]

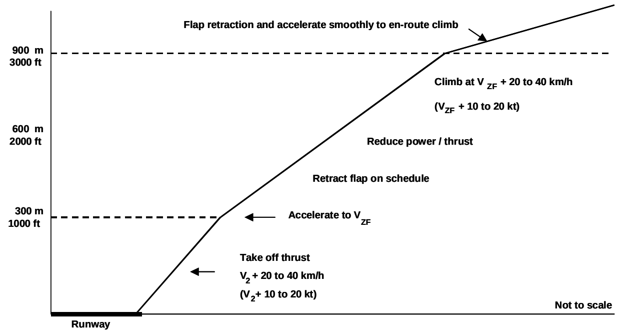

Figure 17: Noise abatement take-off climb - Procedure B [17]

The noise from a departing aeroplane heard at a point on the ground is a function of the noise at source (from both engine and airframe), the distance from the aeroplane and the atmospheric conditions. The source noise and propagation distance are especially influenced by the engine thrust setting and aeroplane configuration (i.e. flap/slat settings). Atmospheric conditions such as air temperature, wind gradient, relative humidity and noise absorption or reflection by the ground also affect the noise reaching a single object on the ground significantly. Noise levels for identical departures can differ, dependent on the trajectory along the flight profile, as a result of chances in atmospheric conditions. The altitude along the flight profile is a function of the aeroplane climb gradient, and this gradient is highest once the flaps are fully retracted. Each type of aeroplane has a specific speed schedule for the flap retraction sequence. To attain the speeds required for flap retraction, the aeroplane is accelerated by reducing its pitch angle to approximately half that used for the initial climb. The time required to complete the acceleration sequence varies by the type of aeroplane and is dependent on the flap retraction time, amount of flap retraction, engine power setting and the speed requirements. The point where the acceleration segment is performed in the departure profile determines whether the procedure will reduce noise over areas near or more distant from aerodrome. A comparative analysis of all possible acceleration segment locations is necessary to reveal the optimum with regard to minimum noise for each aeroplane and runway.

Another important component of the departure profile is the altitude at which the thrust reduction and/or the acceleration segment is initiated. Altitudes of 800, 1000 or 1500 feet above the airport elevation are mostly used by commercial aeroplanes. Simulations and trials at least have shown that the overall noise benefits along the flight path (flight profile) depends on this initiating altitude, on the location of the acceleration segment and on the thrust level after cutback.

Finally, for airports with noise restrictions or noise quota based on fixed monitoring sites, the influence of the initiating altitude is very significant and should be selected by trials with local operators at each aerodrome.

Conclusion

This paper described some of the substantial bottlenecks in the air transport system and the requirements / recommendations to solve operational problems. It is obvious that advanced onboard and ground based technologies and in the same way novel operational concepts are needed right away. But it is also obvious that only a *global top down approach* can renew the current air transportation system. The discussed key-technologies are available. Tests and trials integrated in research programmes have shown that ICAO standards and operational requirements of the resulting equipment are mostly fulfilled. But the national certification processes and the implementation of operational standards and regulations which are under the responsibility of national authorities have to speed up if we really want to meet the air transportation challenges of the future, i.e. to handle the still increasing flows of aeroplanes, freight and passengers in an economic, efficient and safe manner. Achieving the goals and guaranteeing mobility and flexibility by aeroplanes at any time and worldwide means team working of international experts covering the identified problem areas in an integrated way.

References

[1] ICAO *traffic history*, ICAO, Montreal, 2002

[2] Schumacher Jan, *Airbus company presentation*, 2004

[3] AEA, *Delay rates by reasons*, Brussels, 2002

[4] FAA, *aviation capacity enhancement plan*, Washington, 2002

[5] Mensen Heinrich, *Moderne Flugsicherung*, 3rd edition, Springer Berlin Heidelberg New York, ISBN 3-540-20581-0, July 2004

[6] Mensen Heinrich, *Moderne Flugsicherung*, 3rd edition, Springer Berlin Heidelberg New York, ISBN 3-540-20581-0, July 2004

[7] Mensen Heinrich, *Moderne Flugsicherung*, 3rd edition, Springer Berlin Heidelberg New York, ISBN 3-540-20581-0, July 2004

[8] Mensen Heinrich, *Moderne Flugsicherung*, 3rd edition, Springer Berlin Heidelberg New York, ISBN 3-540-20581-0, July 2004

[9] Mensen Heinrich, *Moderne Flugsicherung*, 3rd edition, Springer Berlin Hei-

delberg New York, ISBN 3-540-20581-0, July 2004

[10] ICAO, *airport design requirements, Code F*, ICAO, Montreal, 2002

[11] Airbus, *proposed airport operational standards, Code F*, 2002

[12] A380, *airport planning for airport characteristics*, Airbus SAS, Toulouse, 2002

[13] Schumacher Jan, *company presentation*, Airbus Germany, Hamburg, 2004

[14] A380, *airport planning for airport characteristics*, Airbus SAS, Toulouse, 2002

[15] Schumacher Jan, *company presentation*, Airbus Germany, Hamburg, 2002

[16] ICAO, PANS-OPS, *procedures for air navigation services*, DOC 8186, volume I, part V, chapter 3, aeroplane operating procedures, 5-3, Montreal, 2002

[17] ICAO, PANS-OPS, *procedures for air navigation services*, DOC 8186, volume I, part V, chapter 3, aeroplane operating procedures, 5-4, Montreal, 2002