USE OF AIRCRAFT DERIVED DATA FOR MORE EFFICIENT ATM OPERATIONS

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Abstract

How to make the air-transport system more efficient? The answer is complicated and yet simple: Provide the most accurate data concerning the flight and share that information between the actors in the air transport system! Indeed this is foreseen in the ICAO operational concept adopted at the eleventh Air Navigation Conference in Montreal in September/October 2003.

Provision of Aircraft Derived Data (ADD) is not a new idea, but recent technological progress makes it a far more realistic proposition, especially since most modern aircraft have much more accurate information than the ground system concerning their actual status and its projection to the future.

This paper discusses the ways in which ADD can be used to benefit Air Traffic Management. Potential ADD benefits result from reductions in controller workload through the provision of Controller Access Parameters and also the enabling of more accurate trajectory predictions which should improve the efficiency of air traffic planning and monitoring tools. ADD can also facilitate the interaction of ATC with airline operation centres and airport operations.

The work presented here is part of an ongoing European Union funded NEAN Update Programme (NUP) [1] activity to determine the technical feasibility of downlinking ADD to ground ATC systems using ADS-B and the operational benefits that this would bring. An operational service description has been developed [2] specifying how ADD could be used in ground ATC en-route and terminal area systems. Validation studies are ongoing focusing on the potential improvements to trajectory prediction that can be obtained through the use of ADD and the resulting efficiency benefits on controller decision support tools.

Aircraft Derived Data (ADD)

ADD is a surveillance application in which avionics data are transmitted from the aircraft to the ground (and possibly other aircraft although this is not discussed in this paper). These data may be displayed to the Air Traffic Controller (ATCO) or used in ground processing functions. The main differences between ADD and conventional surveillance techniques such as radar are:

- ADD data are measured on the aircraft. Radar data are measured on the ground at the radar station.
- Much more data are available from ADD than from radar. ADD may supplement radar, by providing additional complementary information, or may even replace it completely.

Many data items are potentially available for downlink on aircraft equipped with modern avionics data busses, and more will become available in the future with the advent of advanced flight management systems. Typical ADD parameters include:

- Aircraft identification (typically the callsign), aircraft equipage, and equipment status
- Current state measurements, e.g. position, bank angle, ground speed and track angle, airspeed and heading, wind speed and direction, etc
- Pilot ‘set’ parameters or targets (referred to as short term intent), e.g. selected altitude, heading, airspeed and next waypoints. Some of these parameters are available from the autopilot while others are available only from a flight management system (FMS).
- Avionics flight path data and calculations, e.g. intermediate waypoints
and estimated times of arrival (ETAs). Such parameters can be obtained from aircraft equipped with an FMS.

Dozens of parameters are available on modern aircraft, especially those equipped with FMS and ARINC data busses. Table 1 illustrates just a few provided by a modern Smiths Industries FMS [3].

Table 1. Sample FMS Data

<table>
<thead>
<tr>
<th>ARINC label</th>
<th>Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>Waypoint</td>
<td></td>
</tr>
<tr>
<td>056</td>
<td>ETA</td>
<td>Hours/ Mins/ 0.1 Mins</td>
</tr>
<tr>
<td>075</td>
<td>Gross Weight</td>
<td>Lbs</td>
</tr>
<tr>
<td>103</td>
<td>FMC Airspeed</td>
<td>Knots</td>
</tr>
<tr>
<td>213</td>
<td>Static Air Temperature</td>
<td>Degrees C</td>
</tr>
<tr>
<td>233-236</td>
<td>Flight number</td>
<td>ASCII characters</td>
</tr>
<tr>
<td>310</td>
<td>Latitude</td>
<td>Degrees</td>
</tr>
<tr>
<td>311</td>
<td>Longitude</td>
<td>Degrees</td>
</tr>
<tr>
<td>312</td>
<td>Ground speed</td>
<td>Knots</td>
</tr>
<tr>
<td>315</td>
<td>Wind speed</td>
<td>Knots</td>
</tr>
<tr>
<td>316</td>
<td>Wind direction</td>
<td>Degrees</td>
</tr>
<tr>
<td>321</td>
<td>Flight path angle</td>
<td>Degrees</td>
</tr>
</tbody>
</table>

The types and quality of data available from a particular airframe depend on the sophistication of the avionics. Modern digital aircraft are more likely to have data available (and more easily accessible) than (older) analogue ones.

A critical complication for the operational utility of ADD is that data quality (e.g. accuracy of position, airspeed, etc) can vary significantly between dissimilarly equipped aircraft. Operational tools and procedures will have to be designed to detect and handle these variations.

ADD Downlink Mechanisms

Figure 1 illustrates the ADD concept. There are several technical means by which ADD can be passed to the ground. Secondary Surveillance Radar (SSR) is a simple example; it allows Mode A (‘squawk’) and Mode C (altitude) codes to be passed to the ground. The aircraft position is calculated at the ground station. The limitations on SSR as a means of providing ADD are that:

- The data items are fixed (Mode A and C codes);
- The number of bits is very limited (11 bits for each item);
- The downlink rate is fixed by the radar rotation rate.
- The accuracy of the position depends on the quality of the ground sensor.

Figure 1. ADD Concept

Other techniques allow more sophisticated transfers and overcome some or all of the SSR limitations. Currently available techniques are:

- **ADS-B**: The aircraft broadcasts data to other aircraft and ground users. The data available depend on the particular ADS-B technology used\(^1\) but typically include aircraft address, position, barometric altitude, callsign, heading, airspeed, ground track, ground speed, etc.

- **Mode S Radar**: An evolution of SSR that allows additional (pre-defined) data items to be downlinked to the ground in response to specific interrogations from the ground station. With Mode S

\(^1\) Three ADS-B technologies have been or are being standardised by ICAO, namely 1090 MHz Extended Squitter, VHF Datalink Mode 4, and the Universal Access Transmitter.
“enhanced surveillance” the list of data items is potentially greatly expandable.

- **ADS-C**: Another ICAO standardised technique whereby aircraft report data items, including position, identity, intent, etc, to the ground over a point-to-point datalink. It has been deployed mainly in oceanic areas using satellite communications [5], but it can also be used over any point to point avionics datalink (VHF, HF etc). ADS-C is presently limited to use in areas of low traffic density because of bandwidth limitations of point-to-point datalinks.

- **ACARS**: This is a datalink technology used primarily by airline operational control that can transmit ADD information to the ground [6]. Widely used by airlines for passing company and operational data, it is not intended for most ATC applications because of its low data rate and unsuitability for safety-critical applications. An upgrade, called VHF Datalink Mode 2, has a higher data rate but will still not be suitable for real-time safety-critical applications [7].

### ADD Operational Use

#### Surveillance in Non Radar Airspaces

Today in non-radar airspace procedural control has to be applied due to the lack of a real time reliable air traffic situation picture. Procedural separation margins are much larger than those permitted in areas with radar control.

ADD downlinked position could be used in non radar airspaces to offer a “pseudo radar” surveillance service. The technical and operational feasibility of such a service has been tested in various ADS projects; see for example [8]. Australia is already introducing operationally an ADS-B system as a means of extending surveillance into non-radar airspace. This will increase safety and enable separation minima reduction at a lower cost than that of an extended radar infrastructure.

Provision of a real time and reliable ADD based surveillance picture increases safety, since the ATCO will have a much better understanding of aircraft positions. Even where procedural control has to be maintained, some delegation of responsibility to aircrew may be possible to perform in trail manoeuvres if airborne reception of ADD is present [9].

#### Controller Access Parameters (CAP)

In the CAP application, selected ADD items are shown on the situation display in order to let the ATCO:

- Know the current aircraft status (typically airspeed/heading) without asking the pilot on R/T.
- Verify that the pilot is conforming to given instructions more quickly than otherwise from the radar or through R/T.

The following CAP items have been included in the Mode S Enhanced Surveillance system [4] that is planned to be introduced operationally in Core Europe:

- **Callsign**: This is normally available from (SSR) Mode A code correlation with the flight plan. The downlinked callsign provides an independent means of aircraft identification and verification.
- **Airspeed** (TAS, IAS or Mach no): Allows the ATCO to learn the aircraft airspeed without radio communication and to check conformance to speed instructions.
- **Magnetic heading**: Allows the ATCO to learn the aircraft heading without radio communication and to check conformance to vectoring instructions.
- **Selected altitude**: Allows the ATCO to check conformance to vertical clearances.

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2 Two forms of Mode S surveillance are to be implemented in Europe: Elementary and Enhanced. The former is being deployed and provides the callsign as well as barometric altitude. Enhanced Mode S [4] will add parameters for controller access and improved tracking (see section on ADD operational use).

3 See [http://www.airservicesaustralia.com](http://www.airservicesaustralia.com)
**Improved Tracking**

Radar tracking algorithms can be slow to detect aircraft turns. ADD can be used to detect turn start and end through data items such as heading, track angle, track angle rate or roll angle. Furthermore, aircraft calculated ground speed is generally more accurate than the estimate of the ground tracking system, especially during turns (existing trackers sometimes assume constant speed during turns).

The improved tracking means that controllers get a more accurate aircraft situation picture and can tell more quickly if pilots are acting on instructions when being vectored.

The following ADD items have been selected in Mode S enhanced surveillance [4] specifically for improving system tracking:

- Vertical rate (Barometric rate of climb/descend or baro-inertial);
- Roll angle;
- Track angle rate;
- True track angle;
- Ground speed

**Conformance Monitoring**

Ground conformance monitoring tools can be used to check aircraft movements against clearances and/or a pre-stored flight plan. Their utility depends on both the reliability of deviation detection and the false alert rate.

Conformance checking tools can use ADD in the following ways:

- ADD improved tracking, described above, with earlier turn detection should improve warning times
- Short-term intent, i.e. autopilot settings, can allow early detection of clearance violations and prevent some false alerts
- Actual Navigation Performance (ANP\(^4\)) indications through ADD could be useful when monitoring adherence to RNAV routes.

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\(^4\) ANP is a measure of the accuracy of the aircraft’s navigation system. It is different from, but related to parameters.

**Safety Nets**

Safety Nets are functions intended to alert ATCOS to potentially hazardous situations in an effective manner and with sufficient warning time so that they can issue appropriate instructions to resolve the situation.

Safety Nets typically include:

- Short term conflict alerts (STCA);
- Minimum safe altitude warnings (MSAW);
- Area proximity warnings (APW);
- Flight level bust warnings.

The most widely used safety net is STCA which is mandatory in many areas and appreciated by ATCOS. STCA requires short term trajectory predictions of up to 2 minutes. This is the maximum time over which it is considered valid to predict aircraft paths based solely on surveillance data.

The utility of safety nets depends on both the reliability of conflict detection and the false alert rate. The false alert rate tends to be highest in the areas where such tools are most needed i.e. in the Terminal Areas and particularly during the approach and climb out phases of flight.

Safety nets should benefit from the more accurate state vector produced by ADD improved tracking [10]. Selected altitude should facilitate flight level bust detection. Finally short term intent can be used to improve the accuracy of trajectory prediction (see below the section on ADD enhanced trajectory prediction) for STCA.

**Controller Decision Support Tools**

ATCO Decision Support Tools (DST) can be distinguished in two categories: basic and advanced. Basic DSTs have been, or are currently in the process of being deployed for operational use in many ATC Centres. They include real-time sequencing tools (like the basic Arrival Management systems), and conflict probe tools (e.g. Medium Term Conflict Detection [MTCD]) used to support the sector planning function. These tools use trajectory predictions based on the flight plan and track data in order to generate metering/sequencing advice and potential conflict alerts. For conflict probe and trial planning
applications, the practical time horizon for ATC use is typically on par with the sector transit time (around 20 minutes in Europe).

Advanced DSTs\(^5\) (currently being under development) provide additional capability to suggest solutions (e.g., the specific ATC clearance/instructions to guide a flight through a conflict resolution). Furthermore such tools support efficient planning of trajectories across multiple sectors.

DSTs that are directly coupled to the use of ADD include MTCD, the Arrival Manager (AMAN) and Multi Sector Planners (MSP).

**Medium Term Conflict Detection (MTCD)**

MTCD assists the ATCO to preview aircraft trajectories and detect potential conflicts. Typically, MTCD reported warnings and alerts are presented to the ATCO on a graphical user interface (see examples in Figure 2). MTCD is a highly desirable and needed tactical and planning tool from the ATCO point of view, as well as from a business perspective. However, its operational introduction has encountered problems. The main problem area is the high number of false conflict alerts that MTCD can generate especially in complex and/or heavily loaded air traffic environments, i.e. where such a tool is needed most.

![Figure 2. Two Examples of How MTCD Information Could Be Presented to the ATCO](image)

**Arrival Manager (AMAN)**

AMAN is an aircraft arrival sequencing tool helping to manage and better organise the air traffic flow in the approach phase. AMAN is directly linked to the airport organisation and the turnaround process because arrival sequencing/metering is important for airline operational control and airport operations (e.g. ground handlers) in order to organise ground flow efficiently\(^6\).

AMAN calculates sequences on the basis of predicted times of arrival at a sequencing point, typically the initial approach fix, which is a navigation point usually 5-10 minutes before landing.

AMAN can use ADD reported times of arrival, and would also benefit from ADD enhanced conformance monitoring (which would allow timely re-sequencing in case of conflict or delays) and trajectory prediction (see following section).

**Multi Sector Planning (MSP)**

MSP tools\(^7\) seek to assist management of metasectors. These tools will co-ordinate the use of conflict detection and resolution tools (such as MTCD and the Conflict Resolution Assistant \([11]\)) with sequencing tools (departure, arrival, and en route managers), and additional tools used for

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\(^5\) Such as the Conflict Resolution Assistant (CORA) developed by EUROCONTROL\([11]\), or the Problem Analysis, Resolution and Ranking (PARR) tool developed by CAASD MITRE for the FAA, etc.

\(^6\) See for example the situation at Stockholm-Arlanda airport \([2]\) where lack of an accurate expected time of arrival well in advance of touchdown is a recognised problem that creates extra work and calls for extra resources in terms of gates, vehicles, personnel etc.

\(^7\) See [http://www.eurocontrol.int/ardeparda/jsp/Ardep014.jsp?Proj=EUR184](http://www.eurocontrol.int/ardeparda/jsp/Ardep014.jsp?Proj=EUR184)
planning across sectors and Flight Information Regions

The objective of MSPs is to ensure that the complexity of future air traffic situations in any sector within the metasector is reduced sufficiently to allow resolution of aircraft conflicts at acceptable levels of ATCO workload.

MSPs are expected to contribute significantly to improve ATM cost efficiency. However a critical prerequisite for such functions is the reliable and efficient operation of the basic conflict detection and sequencing/metering DSTs on which they rely. As explained previously ADD can be used to enhance these basic DSTs. Indeed both conflict detection and sequencing depend on trajectory prediction and that is a function which can use ADD (see following section). Therefore trajectory prediction enhancements through ADD ought to bring benefits also to MSP.

TP Enhancement through ADD

ATM uses Trajectory Prediction (TP) in order to forecast the future progress of individual aircraft. As explained in the previous section, TP is a critical function used in a number of ATCO Decision Support Tools (DST) that are already deployed or planned for deployment. Indeed a common problem is that trajectory prediction functions are often implemented independently in each DST posing a concern for the consistency of the information presented to the controller from the various tools.

DSTs generally require 4-D trajectory prediction capability for look-ahead times ranging from 1-2 minutes for safety nets (such as STCA), to 5-10 minutes for tactical control conflict detection tools, and 20+ minutes for planning and sequencing tools (such as MTCD and AMAN).

TP performance is generally characterised by the trajectory accuracy or uncertainty, the confidence level and the recalculation speed. Trajectory uncertainty tends to increase rapidly with look-ahead time and depends on the operational conditions and the implementation details of trajectory prediction. Advanced DSTs pose more stringent constraints on trajectory uncertainty and recalculation speed than basic DSTs. For example, planning of terminal area transitions requires accurate predictions of cruise-descent and climb-cruise profiles in the presence of tactical manoeuvres for sequencing and spacing. Similarly Continuous Descent Approach (CDA) applications in the terminal area can be particularly sensitive to TP uncertainty.

Current trajectory predictors estimate the future path of a flight on the basis of intent information (obtained from the flight plan), an aircraft performance model, forecasts of meteorological conditions, and ATC constraints (specified by the controller). ADD is a potential additional source of input data to the TP function.

Major sources of trajectory prediction uncertainty are:

- Weather forecast uncertainties;
- Turn dynamics;
- Aircraft performance modeling fidelity – i.e. simplifications, omissions and uncertainty in the mathematical models used to estimate the trajectory;
- Erroneous assumptions on aircraft characteristics, which may vary dynamically (for example aircraft weight) but are usually assigned values derived from flight plan data and/or aircraft performance data bases;
- Tracking and flight mode errors;
- Pilot and controller intent uncertainties.

The impact of each error factor on trajectory prediction accuracy is dependent on the operational conditions. For example, turn dynamics modeling and transient track velocity estimation errors would be most important for flights with many large turns (typically manoeuvres in extended terminal areas).

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8. This paper focuses on the use of TP in Air Traffic Control but TP is also applicable in Air Traffic Flow Management applications, see for example [12].
9. Error vector between the true trajectory and the predicted trajectory, which is usually decomposed into a vertical (altitude) error, an along-track error in the direction of the true velocity vector, and a cross-track error in the horizontal plane normal to the true velocity vector.

10. Probability that a defined level of TP accuracy will be achieved at a given look ahead time.
11. Time needed to perform a trajectory recalculation upon a client request.
while straight level flights might be most affected by weather forecast errors. In general:

- **During descent**: Errors in top-of-descent, wind, speed intent and altitude intent would have the most impact on typical altitude error and along-track prediction errors.
- **During climb**: Performance modeling errors (particularly on weight estimation) and also altitude intent errors affect altitude prediction uncertainty, while wind forecast and speed intent errors are the most important factors affecting the along-track prediction uncertainty.
- **En route**: Current TP trajectory uncertainty has been reported [13] to grow at an average rate of 0.2 NMi per minute-of-look-ahead-time for level unaccelerated flights (and evidently greater for manoeuvring situations).

In practice ATCO/pilot **intent uncertainty** is thought to be the most important source error in today’s TP systems [13], [14], [15]. Therefore trajectory predictability can be improved in two (non-mutually exclusive) ways:

- Redefining operational procedures and airspace design to reduce the uncertainty associated with ATCO/pilot intent uncertainty (e.g. constrain top of descent uncertainty, reduce vectorings out of the route, use of advanced DST providing clearance advisories) etc.
- Ameliorating the quality of input data to trajectory prediction; this is where Aircraft Derived Data can play an important role.

The ground TP function can use ADD as shown in Table 2.

<table>
<thead>
<tr>
<th>ADD Parameter</th>
<th>Use</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 3D position, speed vectors, vertical rate, roll angle/turn rate</td>
<td>ADD enhanced tracking and conformance monitoring systems provide inputs to the TP.</td>
<td>More accurate inputs to short look-ahead (&lt; 2 min) predictions.</td>
</tr>
<tr>
<td>Aircraft weight</td>
<td>Used in aircraft performance modeling.</td>
<td>More accurate climb and descent profile predictions.</td>
</tr>
<tr>
<td>Short term intent</td>
<td>Constraints used in climb, descent and turn prediction.</td>
<td>More accurate turn and climb/descent profile predictions.</td>
</tr>
<tr>
<td>- Aircraft intent, Top of Climb, Top of Descent.</td>
<td>Update the system flight plan on which trajectory prediction is based.</td>
<td>More accurate lateral and vertical trajectory estimates.</td>
</tr>
<tr>
<td>Aircraft reported ETAs</td>
<td>Update or replace ETAs predicted by the ground TP.</td>
<td>More accurate ETA estimates.</td>
</tr>
</tbody>
</table>

Any assessment of ADD improvements on trajectory predictability has to consider the following open issues [2], [13]:

a. Lack of traceable performance requirements for the Trajectory Prediction function;

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12 “Active” advisories would facilitate TP because they provide accurate controller intent for tactical manoeuvres,

13 3-D waypoints (known navigation locations) or trajectory change points.

14 The FMS has knowledge of pilot intent (selected flight plan), the desired vertical profiles (entered in FMS database) and also knowledge of the navigation mode. When engaged the FMS can compensate for wind variations through its closed loop with engine and flight controls. The ground TP does not know when lateral or vertical mode is disengaged, e.g. when the aircraft is being vectored, and cannot adjust its predictions for periods where the flight plan is not followed. On the other hand the ground TP has better knowledge of ATCO intent and future wind conditions.
b. Unclear performance of current Trajectory Predictors (although a significant quantity of results exists for many individual applications);
c. Unknown minimum flight data quality.

Ideally TP performance requirements should be set on the basis of DST design requirements in the framework of a full top-down system design from ATM concept to the definition of minimum flight data quality.

**Operational Benefits from ADD**

The effectiveness of air traffic control depends on controller and pilot Situation Awareness. ATCOs acquire situation awareness through a traffic situation display, associated support tools, and communications (through R/T) with the pilots.

The quality of today’s air traffic data presented to the ATCO varies and the usability of support tools depends on the quality of these data in combination with the algorithms used in the support tools. ADD can augment the information presented on the ATCO situation display (see section on Controller Access Parameters) and they can also be input through the tracking and trajectory prediction functions to controller DSTs. ADD quality depends on aircraft equipage but it tends generally to be more up to date and accurate than information extracted from flight plans and other ground data stores.

Presentation of ADD on the ATCO work position situation display, i.e. the human machine interface, is not discussed in this paper. Irrespective of the HMI used, the display of CAP reduces the need for pilot/controller R/T, and ensures greater reliability in their information exchanges (a safety benefit). Reductions in pilot/controller R/T use imply not only workload reductions but also a reduction in the use of the aeronautical VHF voice system which is approaching congestion in heavily loaded air traffic areas [4].

ADD fits nicely in the context of the operational concept for ATM that was endorsed and adopted by the ICAO member states at the Air Navigation Conference 11 in 2003. Seven conceptual changes were outlined and ADD is a significant contributor in a number of these, including, traffic synchronisation, demand and capacity balancing, conflict management and airspace user operations. Operational benefits from ADD are foreseen in the following areas:

- Safety;
- Strategic and tactical planning, through MSP and MTCD;
- Arrival management;
- Flight time spent in holding patterns;
- Optimization of airport resources;
- Collaborative decision making i.e. prioritisation;
- Fleet management.

Safety nets should benefit from ADD because of the more accurate tracking and short term trajectory prediction resulting in lower false alert rates and improved conflict warning times for the ATCO. Such improvements will certainly ameliorate safety net usability and increase ATCOs confidence in them, thus facilitating a wider use of these tools (although STCA use is well established already).

Strategic and tactical planning tools will benefit from ADD improvements in trajectory prediction which should reduce prediction uncertainty and therefore false conflict alert rates. The usability of ATC tools like MTCD and therefore MSP should increase. If the reliability of these tools increases and they become more acceptable to ATCOs there is likelihood that there will be an impact on airspace design i.e. use of larger sectors allowing more optimized air traffic flows. This also means a more efficient use of the airspace.

Arrival management should benefit from ADD through the improved reliability and performance of conformance monitoring and the increased accuracy of ETA estimates. Conformance monitoring is an

15 Situation awareness can be defined as follows “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” [16].

important contributor to arrival management operation because it detects turns, delays, and deviations and consequently determines the timing of AMAN advisories and hence ATCO instructions to the aircraft. AMAN ability to line up aircraft for approach in an optimal way using minimum ATCO effort and exploiting aircraft capabilities should result in cost efficient operations where delays are minimized and runway usage is maximized.

Improved trajectory predictability would be very useful in cases where aircraft are to be allocated a requested time of arrival (RTA) and delegated the responsibility of meeting this RTA over prescribed conflict-free 4-D trajectory. In such a scheme, calculation of realistic RTAs by the ground TP function is critical. This approach has been tested in large scale flight trials\textsuperscript{17}. RTA based arrival sequencing, imposes stringent requirements on conformance monitoring along the prescribed 4-D routes, and ADD could facilitate this task [2].

Airport organisation would benefit greatly from more accurate and up-to-date ETA and even more so from better conformance to an RTA. ETAs need to be updated regularly and made available to the ground system, so that the airport organisation and airline operational control can optimize their resources in a cost efficient way. Ultimately the aircraft could be notified about the RTA well before starting up on outstation.

The use of holding patterns is undesirable for all air traffic management actors. It is costly in terms of fuel, the environment, re-bookings, delays etc. ADD enhancements to arrival sequencing and traffic planning tools should enable more efficient planning exploiting the available capacity and allowing early intervention when comparing the ETA with the actual slot. If there is a need for change of the ETA, a RTA should be distributed to the aircraft. Once again the true aircraft-maintained ETA is crucial for cost efficient operations.

Collaborative Decision Making [18] needs to use the most accurate information in order to serve its users. For applications like slot swapping and change in prioritisation from the airline point of view the need for accurate and precise data such as ETA is obvious.

Efficient real time fleet management is a key to successful airline operations. The critical requirement is to maximise the usage of the aircraft in combination with minimum time on the ground. Fleet management not only needs accurate ETA but would also benefit from more accurate and frequent weather reports (ADD can be used to collect weather data in order to improve meteorological forecasts for ATM).

**NUP2 ADD Tiger Team**

The North European ADS-B Network (NEAN) Update Programme Phase II (NUP2)\textsuperscript{18} is a European Union funded programme aiming to “establish a European ADS-B network based on global standards and supporting certified applications and equipment in synergy with the European ATM concepts providing benefits to ATM stakeholders” [1].

The NUP ADS-B infrastructure was developed originally under the NEAN project (1995-1998) using the VHF Datalink Mode 4 technology. NEAN was followed by NUP Phase 1 (1999-2001), which formed local teams, called “Tiger Teams” to define a range of ADS-B applications that can be implemented over this infrastructure. NUP2 (2001-2005) has continued the development and large scale validation initiated under NUP1. The five-station ground network established in Phase 1 is being expanded to include up to thirty sites providing the basis for a large north European large-scale validation network. The NUP2 network will be partly connected to ATC systems and planning centres and will provide various services

\textsuperscript{17} In one such trial [17], a total of 33 flights of revenue aircraft (Boeing 737 New Generation) were used. Subsequent analysis indicated that properly equipped aircraft can reliably predict and maintain a 4-D trajectory over an entire flight in real-world fleet operations. Time-of-arrival errors at waypoints located at the top of the Standard Arrival procedures were demonstrated to be less than 7 seconds with a standard deviation of 4.8 seconds. In cases targeting the runway with an RTA constraint, errors were bounded to 21 seconds with a standard deviation of 12.7 seconds.

\textsuperscript{18} See \url{http://www.nup.nu}. Some of the NUP2 partners are: Swedish CAA (LFV), German CAA (DFS), Danish CAA, Norwegian CAA, Icelandic CAA, Finnish CAA, French CAA (STNA), Austrocontrol, Belgocontrol, Airbus, and EUROCONTROL.
to ATC and aircraft, including ADS-B, Flight Information Broadcast, Traffic Information Broadcast and GNSS augmentation.

NUP2 supports the following applications [2]:

- **Cluster A**: Non Radar environment (ADS-B surveillance in non radar airspace).
- **Cluster B**: Off Shore Operations (helicopter operations with ADS-B).
- **Cluster C**: Airport surface movement operations (surveillance and ground movement control using ADS-B).
- **Cluster D**: Air to Air Applications (station keeping, enhanced visual acquisition).
- **Cluster E**: ATC Integration (Cooperative Air Traffic Services in Extended Terminal Area, and Aircraft Derived Data).

NUP2 expanded the role of Tiger Teams (TT) to develop coordinated operational service descriptions and validation plans and deal with preparation for operational introduction of these applications.

A Tiger Team was established specifically for the ADD application. The NUP2 ADD TT developed an ADD Operational Service Description (OSED) [2], addressing the use of aircraft derived data to enhance the controller situation display and DSTs in three specific operational environments (namely Arlanda terminal area, Malmo en-route sector, and Maastricht upper en-route airspace).

The NUP2 ADD TT has also developed a plan for validating the ADD OSED [19] and has begun conducting validation exercises starting with the use of ADD to enhance trajectory prediction. This paper summarises the findings of this work. The next exercise foreseen will validate the use of ADD in support of curved RNAV approaches to Arlanda19.

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19 The work of NUP2 ADD is accessible via the EUROCONTROL OneSky Online facility at www.eurocontrol.int.

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**Conclusions**

Aircraft Derived Data enable improvements in the situation displays and automation tools available to the ATCO which should result in worthwhile operational benefits. ADD should be beneficial not only to the ATCO but also to airline operations, and airport organisation. ADD is a contributor in the air transport cooperative case, which should enable increased predictability for the whole system and hence allow for safe and cost efficient operations. Therefore, the introduction and use of ADD should be an opportunity to improve and strengthen the cooperative case between air and ground.

The use of ADD can be seen as connecting the aircraft to the business process. For the communication to and from the aircraft different means could serve. The important thing is to get the most accurate data concerning a flight and its future requirements to the ground system. The ground system (involving ATC, AOC and Airport) then analyses how this information interacts with other adjacent information and if needed changes are communicated to the aircraft.

Trajectory predictability is a fundamental constraint in ATM operations. ADD can be used to improve the operation of the trajectory prediction function, but further analysis and experimentation work is required to evaluate their impact. The NUP2 ADD Tiger Team has begun such an effort and there are other FAA and EUROCONTROL initiatives in this area. A bottom-up understanding of TP performance needs to be carried in parallel with a top-down system design approach (i.e., from ATM concept development down to Decision Support Tool design). In other words a combined approach is required: Top-down for concept development and tool design on the one hand, and bottom-up analysis of the achievable performance of Trajectory Prediction function. Only with such a comprehensive approach can one hope to achieve the necessary compromises between the TP requirements of future DSTs and the TP performance that is achievable within a given time frame and operational context.

The first step in the recommended approach should be a comprehensive trajectory accuracy sensitivity study to be performed on all the TP inputs and in parallel with that a study of the sensitivity of the automation tools to TP
predictability. This work should permit identification of the optimum TP predictability improvements and definition of the requirements of DSTs on TP performance.

References
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Abbreviations
ACARS Aircraft Communications Addressing and Reporting System
ADD Aircraft Derived Data
ADS-B Automatic Dependent Surveillance - Broadcast
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADS-C</td>
<td>Automatic Dependent Surveillance - Contract</td>
</tr>
<tr>
<td>AMAN</td>
<td>Arrival Manager</td>
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<tr>
<td>ANP</td>
<td>Actual Navigation Performance</td>
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<tr>
<td>AOC</td>
<td>Airline Operational Control</td>
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<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
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<tr>
<td>ATCO</td>
<td>Air Traffic Controller</td>
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<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
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<tr>
<td>CAP</td>
<td>Controller Access Parameter</td>
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<tr>
<td>CDA</td>
<td>Continuous Descent Approach</td>
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<tr>
<td>CORA</td>
<td>Conflict Resolution Assistant</td>
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<tr>
<td>DMAN</td>
<td>Departure Manager</td>
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<tr>
<td>DST</td>
<td>Decision Support Tool</td>
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<tr>
<td>EMAN</td>
<td>En-route Manager</td>
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<tr>
<td>ETA</td>
<td>Estimated Time of Arrival</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FMS</td>
<td>Flight Management System</td>
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<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
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<tr>
<td>MSAW</td>
<td>Minimum Safe Altitude Warnings</td>
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<td>MSP</td>
<td>Multi Sector Planning</td>
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<tr>
<td>MTCD</td>
<td>Medium-term Conflict Detection</td>
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<tr>
<td>NEAN</td>
<td>North European ADS-B Network</td>
</tr>
<tr>
<td>NUP</td>
<td>NEAN Update Programme</td>
</tr>
<tr>
<td>OSED</td>
<td>Operational Services and Environment Definition</td>
</tr>
<tr>
<td>RNAV</td>
<td>Area Navigation</td>
</tr>
<tr>
<td>RTA</td>
<td>Required Time of Arrival</td>
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<tr>
<td>SA</td>
<td>Situation Awareness</td>
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<tr>
<td>SSR</td>
<td>Secondary Surveillance Radar</td>
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<tr>
<td>STCA</td>
<td>Short-Term Conflict Alert</td>
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