Appendix H Demonstration Exercise EXE-VLD-06-003 (Heathrow Long Range Target Times) Report

H.1 Summary of the Demonstration Exercise EXE-VLD-06-003 Plan

As in DEMOP PJ25

H.1.1 Exercise description and scope

The purpose of the demonstration was to demonstrate the extent to which an AMAN prototype designed to stream arrivals to an FIR boundary coordination point by using Target Times Over the metering point could be successful in the real world. This demonstration was achieved as a shadow mode exercise using real world traffic information for all Heathrow Airport arrivals during 3-11 April 2019.

Issue to be Solved

In current operations, controllers responsible for the en route phase of flight use best endeavours to provide longitudinal streaming for aircraft approaching the descent phase of flight, i.e. they endeavour to provide sufficient time separation between aircraft approaching the Standard Arrival Route (STAR) that aircraft can descend continuously. Where this does not occur, and aircraft approach the descent phase too close to each other, they must be vertically separated. This creates significant controller workload during the descent phase as it requires the second aircraft to either by given lateral separation or else be given a 'step' descent, where the aircraft is cleared to descend a few thousand feet at a time, only being cleared to a lower level once the aircraft ahead has descended sufficiently.

The SESAR PCP requirement is that airports increasingly specify STARs in terms of Required Navigational Performance (RNP). This enables routes to be placed closer together and increases the aircraft's ability to optimise its descent. However, it also restricts the controller's ability to use lateral headings to help stream arrival aircraft.

Moreover, Heathrow operates extended arrivals management techniques whereby adjacent ANSPs slow aircraft when delay in the TMA is predicted. This objective can conflict with the need to stream arrivals prior to descent and lead to some aircraft being slowed for extended arrivals management and then sped up for streaming purposes.

SESAR Solution

The solution to the issues above is to develop the extended arrivals management capability so that it calculates target times for the pre-descent point, which at Heathrow is also the FIR boundary coordination point for many arrival flow directions. The operational AMAN already considers runway wake vortex sequence and delay apportionment to en route; the SESAR prototype AMAN additionally considers whether two or more aircraft are predicted to cross the pre-descent metering point within a parameter time value. In this shadow mode exercise the required time separation parameter was set to 90 seconds. If no delay was predicted, the first aircraft was unaffected, and the second aircraft received a target time designed to slow it to achieve the required time separation. If delay was predicted, the second aircraft was slowed to the greatest extent possible, and the first aircraft was slowed enough to achieve the required time separation.

Trajectory Data

For the concept described above to work, it is essential to have accurate underlying trajectory data. If the trajectory data is inaccurate, the target times are likely to be incorrect and may be unachievable by the aircraft. Inaccurate data may even take a benign situation and create a conflict, for example, if AMAN thinks that Aircraft A is due to cross the metering point ahead of Aircraft B but the time separation is too small, it may try to slow Aircraft B. If the trajectory data is incorrect and B is actually ahead of A, the resulting target times may make the situation worse.

For that reason, this demonstration included an assessment of two potential new sources of trajectory data which were compared against the baseline source of trajectory data, the Network Manager's ETFMS system. Maastricht UAC operates an 'XMAN Portal' that combines its own FDP trajectory data with ADS-B data and other data sources to create a mixed-source set of 'fused' data. Reims is deploying its new FDP Co-Flight system which uses its own new trajectories, and which are updated by ATCO control instructions for aircraft within its own area of responsibility.

Extended Arrivals Management Long-Range Horizon

A long-range extended arrivals management horizon of 500nm (approximately 85 mins) was used in this demonstration as this provided sufficient distance to enable aircraft to adjust their speed in response to a target time and achieve the required time separation at the metering point.

Validation Methodology

ETFMS data was selected as the most suitable source of trajectory data (see results section) and fed into the AMAN prototype. As aircraft crossed the extended arrivals management horizon of 500nm, AMAN checked whether the estimated time at the metering point meant that it was likely to breach the required 90 second time separation behind the aircraft ahead of it on the same arrival flow. If this was the case, AMAN calculated a target time to provide the required separation. In this shadow mode demonstration, these target times were not issued to any aircraft, which continued in accordance with current operational procedures.

The evolving AMAN calculations, including the estimated or 'undisturbed' trajectory, together with the 'target' trajectory, were published as SWIM arrival sequence service data, which was recorded. The actual crossing times at the metering point were also recorded. This meant that it was possible to calculate in post-operations analysis how the predicted trajectories compared with actual trajectories, whether the AMAN solution would have worked in reality, and whether the target times were achievable.

H.1.2 Summary of Demonstration Exercise EXE-VLD-06-003 Demonstration Objectives and success criteria

The objectives and success criteria for EXE-VLD-06-003 are provided in the xStream DEMOR main document in chapter 3.4 "Summary of the xStream Demonstration Plan".

H.1.3 Summary of Demonstration Exercise EXE-VLD-06-003 Demonstration scenarios

The reference scenario comprises all aircraft all aircraft arriving at London Heathrow Airport during 3-11 April 2019. The solution scenario is identical, except that an AMAN prototype calculated target trajectories to demonstrate the extent to which the AMAN solution would have solved the real - arrival streaming requirement.

H.1.4 Summary of Demonstration Exercise EXE-VLD-06-003 Demonstration Assumptions

The assumptions concerning EXE-VLD-06-003 are provided in the xStream DEMOR main document, in chapter 3.4 "Summary of the xStream Demonstration Plan".

H.2 Deviation from the planned activities

The shadow mode trial ran 3-11 April 2019. During this period, around 6046 aircraft arrived at Heathrow. The exercise recorded usable data for 5330 aircraft. Data associated with approximately 716 aircraft was unusable as the metering point (boundary coordination point or COP) differed from that which was planned. One cause of this is when an aircraft is tactically rerouted to a different holding stack for balancing purposes after the arrival manager (AMAN) has planned the sequence at the E-AMAN boundary.

H.3 Demonstration Exercise EXE-VLD-06-003 Results

H.3.1 Summary of Demonstration Exercise EXE-VLD-06-003 Demonstration Results

The table below shows how 06-03 has met the expected KPI objectives described in the PJ25 Demo Plan.

	KPI	Ex 06-03
OBJ-VLD-01-001	Safety	OK – delay transferred into lower risk factor airspace
OBJ-VLD-02-001	Predictability & Punctuality	OK – punctuality maintained
OBJ-VLD-03-001	Environment	OK – Fuel and emissions reduced
OBJ-VLD-04-002	Cost Efficiency ANSP	OK – controller workload reduced
OBJ-VLD-05-002	En Route Capacity	OK – controller workload reduced

1. Results per KPA

a. KPA Safety

i. Quantitative Assessment

1308 minutes of delay would have been transferred out of the TMA and into en route airspace during the trial; the annualised number is 53044 minutes. In many ANSPs, there is a higher risk associated with time spent in the TMA compared with time spent in en route airspace and therefore while the main benefit is environmental, there is also a safety impact.

The explanation and analysis of the table below is in the later chapter entitled Exercise Analysis.

Count 0 mins	5320		
Count 0-1 mins	264	delay sum 0-1	117
Count 1-2 mins	164	delay sum 1-2	240
Count 2-3 mins	273	delay sum 2-3	774
Count > 3mins	25	delay sum>3	88
Total Trial TTAs	726	Trial COP Delay (mins)	1308
		Annualised COP delay (mins)	53044
(Avg holding fuel 45.9kg/min)		(Fuel price £445/tonne)	
Trial fuel saving (tonnes)	60	Trial fuel cost £	26715
Annualised fuel saving (tonnes)	2435	Annualised fuel cost £	1083455
Trial numbers arrivals (April 2019)			
3rd	673		
4th	673		
5th	680		
6th	638		
7th	668		
8th	692		
9th	675		
10th	683		
11th	684		
Trial Number arrivals	6044		
Annualised arrivals	245118		

Figure 1 - Reduction in TMA Airborne Holding

ii. Qualitative Assessment

There was no qualitative assessment during this shadow mode demonstration.

b. KPA Predictability and Punctuality

i. Quantitative Assessment

The operational Heathrow extended arrivals management system uses ETFMS data. However, given the importance of accurate trajectory data to any concept attempting to carry out a function as precise as arrival streaming, two alternative sources of trajectory data were explored

The Maastricht UAC XMAN Portal system, that combines MUAC FDP trajectory data with ADS-B data and data from other sources, made its data available. The volume of messages relating to Heathrow arrivals is shown below, where EFD stands for the Eurocontrol Network Manager ETFMS data and eEFD for the MUAC data.

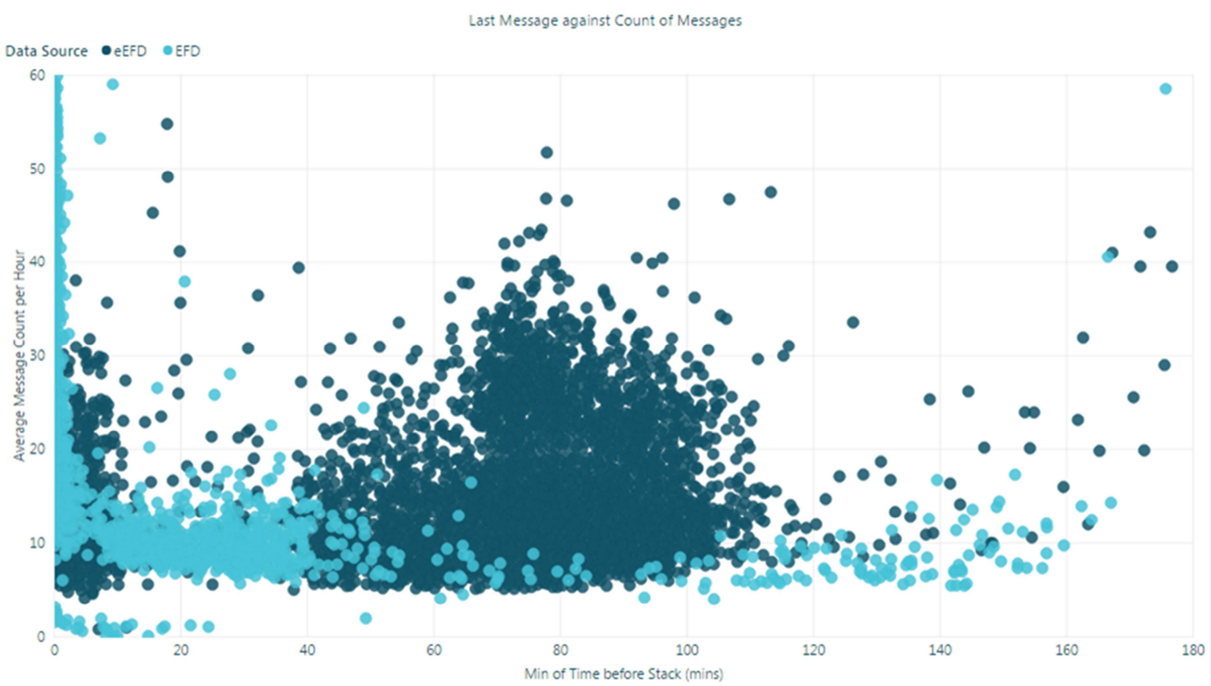

Figure 2 - MUAC Message Count

The message accuracy compared with ETFMS is shown below.

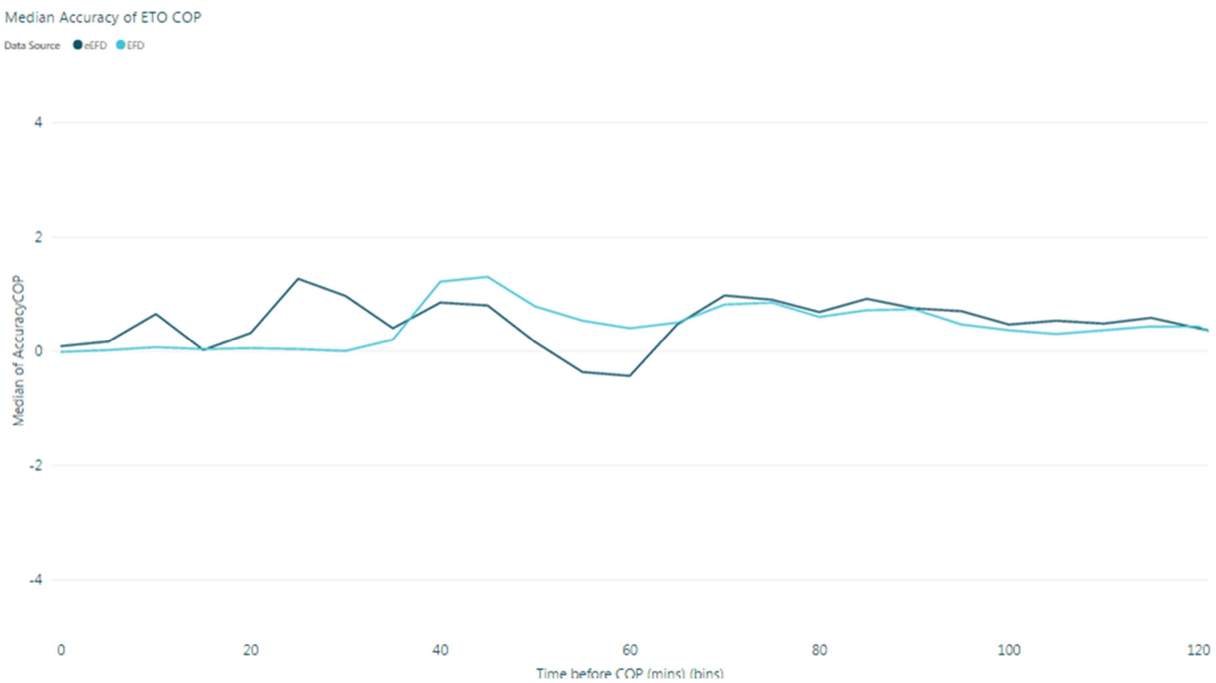

Figure 3 - MUAC XMAN Portal Message Accuracy

The Reims UAC Co-flight FDP trajectory data accuracy was also explored. At the time of assessment, the system was still in its early stages of deployment, and its accuracy had not yet reached its full potential. Use of a neighbouring ANSP's trajectory data is in principle, a good thing to do as it should immediately update in response to tactical actions by either the controller or the pilot.

As neither alternative data source offered a significant improvement upon ETFMS, the decision was made to stick with ETFMS data, available from NM via the existing EFD feed, as this reduced engineering complexity and associated cost and time.

ii. Qualitative Assessment

No qualitative assessment of predictability factors took place.

c. KPA Environment

i. Quantitative Assessment

1308 minutes of delay would have been transferred out of the TMA and into en route, saving airlines 60 tonnes of fuel. The annualised figures are 53044 minutes and 2435 tonnes of fuel.

The explanation and analysis of the table below is in the later chapter entitled Exercise Analysis.

Count 0 mins	5320		
Count 0-1 mins	264	delay sum 0-1	117

Count 1-2 mins	164	delay sum 1-2	240
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Count > 3mins	25	delay sum>3	88
Total Trial TTAs	726	Trial COP Delay (mins)	1308
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11th	684		
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Annualised arrivals	245118		

Figure 4 - Fuel and Environmental Emissions Reduction Results

ii. Qualitative Assessment

No qualitative assessment of environmental factors took place.

d. KPA Cost Efficiency

i. Quantitative Assessment

The controller workload associated with streaming arrivals prior to descent would have been reduced by a little over one third. If the aircraft in receipt of TTOs to the pre-descent metering point had complied with their TTOs, this would have solved 219 of the 598 occasions when AMAN predicted, based upon ETFMS trajectory data, that aircraft would have crossed the metering point within 90 seconds of each other. Follow up work will continue to understand why TTOs were not issued to solve most of the other conflictions.

The explanation and analysis of the table below is in the later chapter entitled Exercise Analysis.

ETO not equal to TTO	713
ETO equal to TTO	4616
Number of aircraft	5329
PLAN	
Number ETO under-sep (calc TTA)	598
TTO good sep, good delay	219
TTO excess delay	30
TTO under-sep	92
No TTO issued	257
REALITY	
Number ATO under-sep	364
TTO good	497
TTO excess delay	184

Figure 5 - Arrival Streaming Results

ii. Qualitative Assessment

No qualitative assessment of cost efficiency factors took place.

e. KPA Capacity

i. Quantitative Assessment

The figure below shows graphically the numbers of aircraft predicted to arrive within the 90 second required time separation at a pre-descent metering point. The graph on the left shows the numbers of aircraft present in the system at 85 minutes prior to landing time, i.e. aircraft yet to take off from in-horizon airports are not counted, although note that the AMAN does include those aircraft with a DPI-ATC (taxiing) status at A-CDM airports. The graph on the left compares the ETFMS feed to the AMAN prototype system, compared with the operational AMAN system. These show that of approximately 5200 aircraft, approximately 600 aircraft are predicted to be within 90 seconds of another aircraft at a pre-descent metering point. This represents controller workload, either by the en route controller prior to descent, or by the controller managing the descent phase after the metering point.

The graph on the right shows the improvement made by the prototype AMAN, i.e. if aircraft had followed the TTOs accurately, controllers would have had approximately one-third fewer streaming-related controlling tasks to carry out. It is acknowledged that this is a mathematical exercise not fully representative of operational reality where other aircraft and factors may play a part in arrival streaming and the associated workload.

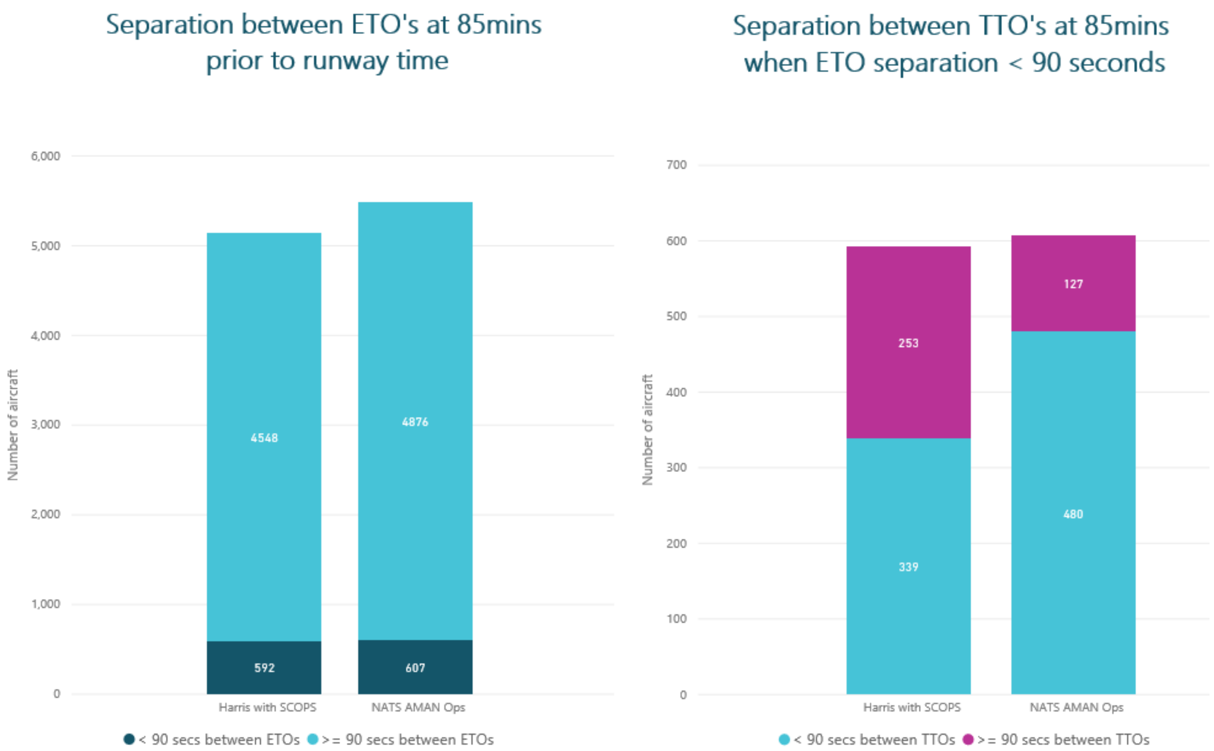

Figure 6 - Numbers of Streaming Interactions Solved by TTOs

ii. Qualitative Assessment

No qualitative assessment of capacity factors took place.

2. Results impacting regulation and standardisation initiatives

These results do not impact upon regulation or standardisation initiatives.

H.3.2 Analysis of Exercises Results per Demonstration objective

1. EXE-VLD-06-003 OBJ-VLD-01-001 (Safety) Results

For many ANSPs, the level of risk associated with operations in the TMA is higher than the level of risk associated with operations in en route airspace. This means that there is a benefit to reducing the amount of time spent by aircraft in the TMA compared with in en route airspace. This shadow mode exercise has demonstrated the extent to which use of long range TTOs can transfer delay out of the TMA and into en route.

2. EXE-VLD-06-003 OBJ-VLD-02-001 (Predictability and Punctuality) Results

Adjusting the speed of arriving aircraft as part of eAMAN procedures does not reduce predictability or punctuality at the runway provided that the majority of arriving aircraft participate in the process. If the majority of aircraft are slowed, the numbers of aircraft overtakes is minimal. Transferring delay from the TMA and into en route does not affect an aircraft landing time as it only changes the portion of sky where excess delay is spent.

3. EXE-VLD-06-003 OBJ-VLD-03-001 (Environment) Results

The modelling follows established Extended Arrivals Management procedures whereby the amount of fuel used in TMA airborne holding is compared with the fuel saving made by flying slower in en route airspace. This depends on the aircraft mix; heavy aircraft tend to save in the region of 55 kg / min whereas medium aircraft save around 35 kg/min. At Heathrow, the traffic mix is approximately equal between aircraft categories. The current operational XMAN procedure saves around 3600 tonnes of fuel each year, using a 350nm eAMAN horizon. This exercise, based on a 500nm horizon, would have saved 2435 tonnes, i.e. there would have been a reduced fuel saving. Three factors play a part in this. Using a 500nm horizon rather than a 350nm horizon means that a significant number of aircraft are not yet airborne as they depart from in-horizon airports, and therefore the level of predicted delay is less at 500nm; this means that fewer aircraft meet the delay threshold to receive a TTO. Secondly, this exercise adds a streaming requirement, meaning that some aircraft are not slowed down, even though they might meet the delay threshold, in order to ensure streaming takes place. However, use of a longer range means that any aircraft slowed down absorb more time, which should therefore increase the amount of delay transferred out of the TMA. Clearly the first two factors outweigh the third factor. This work will be continued in PJ01 Wave 2, where similar trials using a 350nm horizon will be carried out to see to what extent the in-horizon demand factor plays a part.

4. EXE-VLD-06-003 OBJ-VLD-04-002 (Cost Efficiency ANSP) Results

It is hard to claim that ANSP costs will be reduced directly as a result of a reduced arrival streaming workload. Nevertheless, if this concept could be widely adopted and subsequently led to a reliable and consistent reduction in workload, then in theory either capacity could be increased for the same number of controllers, or a reduced number of controllers could provide a service to a similar volume of aircraft. The shadow mode data has shown that the number of aircraft pairs (or greater) that flew over the pre-descent metering point within the 90 second time parameter was reduced by around a third. This represents significantly reduced workload, either by the en route controllers setting up the stream prior to descent, or even more so by the descent controller, as streaming aircraft who are too close to each other in descent requires use of lateral heading or 'step' descent clearances, both of which are workload-intensive as they require constant monitoring.

Further development is required in PJ01 Wave 2 to determine why the AMAN prototype did not issue more TTOs, even at the planning stage where aircraft were 85 minutes from landing (500nm eAMAN horizon). The data shows that of 598 expected under-separations (based upon ETFMS trajectory data while aircraft crossed the 500nm horizon), AMAN issued 219 TTOs which, if followed, would have solved the under-separation. 30 TTOs required too much delay to be absorbed, and 92 would have been insufficient to solve the problem. Note that of these 92, some were because it was impossible to provide sufficient slow down time over the distance available, for example because several aircraft were arriving in a 'bunch'. On 257 occasions, no TTO was issued and this is being investigated.

5. EXE-VLD-06-003 OBJ-VLD-05-002 (Capacity En Route) Results

The controller workload reduction is descried above as part of ANSP cost reduction. Reduced workload ultimately either increases capacity or reduces costs or a mix of both.

H.3.3 Unexpected Behaviours/Results

The prototype AMAN did not issue a TTO on a significant number of occasions when it was expected to, i.e. when an under-separation at the metering point was predicted. This is being investigated.

H.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

The shadow mode exercise is representative of Heathrow arrivals as it used real life traffic data throughout the period 3-11 April 2019. It is limited in that because aircraft did not actually attempt to fly the TTOs, there is no evidence of the extent to which aircraft could have successfully met their TTOs. The TTOs were calculated using operational eAMAN experience, i.e. based upon a maximum slow down of Mach 0.04, as used by the existing Heathrow XMAN process. Hence, the TTOs should be 'flyable'. However, factors such as conflicting aircraft meaning that neighbouring ANSPs are unable or unwilling to allow aircraft to fly the TTOs may affect these results.

2. Quality of Demonstration Exercise Results

Of just over 6000 aircraft that arrived at Heathrow during the trial period, the post-ops analysis of the arrival streaming capability could only be completed on just over 5300 aircraft. In many cases, this was because the aircraft were planned to use one coordination point (pre-descent metering point) and used another (often to balance traffic). This will affect the validity of the results somewhat and will need to be addressed in any future work.

3. Significance of Demonstration Exercises Results

These results are limited to the extent that they are not necessarily operationally realistic. As discussed above, while the TTOs were calculated to be achievable, other factors, for example conflicting aircraft, could prevent aircraft from complying with their times.

H.4 Conclusions

The current Heathrow extended arrival management procedure (Heathrow XMAN) has operated successfully for several years, transferring 66,000 minutes of delay per annum out of the TMA and into en route airspace, saving airlines over 3600 tonnes of fuel and the associated emissions. (Note that this exercise has not addressed the reduced speed descent aspect which in current operations transfers a further 55,000 minutes and saves a further 3000 tonnes of fuel in addition to the XMAN phase).

However, the current procedures, while efficient at saving fuel, do not address the issue of arrival streaming, which is expected to become an even bigger issue once ANSPs deploy RNP-defined arrival routes (STARs). Use of RNP STARs remove one part of the controller's toolkit when trying to provide arrival streaming, as the use of lateral headings becomes limited. This increases the requirement to ensure arrival streams are successfully set up prior to descent, preferably with sufficient time between aircraft to allow them to descend continuously, reducing controller workload and improving aircraft fuel performance.

Use of TTOs as part of extended arrivals management procedures to take account of both delay absorption and arrival streaming has the potential to reduce controller workload, support deployment of systemised RNP-defined arrival routes, and save fuel. However, there are a number of questions arising from this shadow mode trial, the main two being what eAMAN horizon offers the best trade off between ability to absorb time and having the full demand picture, and the second question relating more to the AMAN performance. Moreover, streaming into systemised airspace only solves part of the total problem. Streaming into systemised airspace in a way that accounts for aircraft arriving from other directions would in theory help reduce the scale of the task in merging flows of aircraft within the TMA. These aspects are planned to be taken forward into PJ01 Wave 2.

Nevertheless, confidence in the concept has been gained from using the AMAN prototype during 11 days in April when real-life traffic data was used, and where if aircraft had followed the TTO advice, the level of controller arrival streaming workload would have been reduced by one third.

H.5 Recommendations

H.5.1 Recommendations for industrialization and deployment

This work has shown sufficient promise to warrant its continuation and extension into SESAR Wave 2. As the PJ01 Wave 2 plans will add considerable complexity in the form of considering the descent phase and TMA flow merge task, work to develop the required functionality should be carried out as an R&D activity, prior to any further shadow mode tests using real-life traffic data.

H.5.2 Recommendations on regulation and standardisation initiatives

There are no recommendations on regulation or standardisation. This work follows the accepted SESAR principles and European ATM Master Plan and is not recommending changing any part of these.