



Impact of ATC speed instructions on fuel consumption and noise exposure: an assessment of real operations in Zurich

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Abstract

Approach operations at busy airports are louder and less fuel efficient than they technically could be. Carrying out a safe approach under fluctuating wind and weather conditions while following individual air traffic control (ATC) instructions imposes a significant workload on the flight crew, especially with the limited systems support and information availability on the flight deck today. The SESAR exploratory research project DYN-CAT (Dynamic Configuration Adjustment in the TMA) aims to highlight the impact of current approach operations on the environment based on all relevant data sources (on-board operational data, ATC commands, noise measurement data, surrounding traffic and weather information) allowed to evaluate individual approach operations in their full context, exemplarily for the Airbus A320 at Zurich airport. The evaluations performed are a unique opportunity to analyse the impact of ATC instructions on fuel consumption and noise exposure during real operations. The results showed that speed instructions, especially when given early during the transition phase, lead to high fuel consumption, due to the long-time flight in low speed levels correlated to earlier usage of Flaps configurations. A mean difference of almost 50 kg in fuel burned is observed when comparing the flights with speed restrictions to those without. On the other hand, speed restrictions provide a well-defined airspeed guidance for the pilots during transition and final approach, which leads to lower usage of speed brakes and also to lower speed levels for the landing gear extension. The less speed restrictions were given to the pilots by ATC, the higher was the usage of speed brakes during the final approach, and also the landing gear deployment was performed at higher speed levels, which *ceteris paribus* contributes significantly to the noise exposure and noise footprint. Based on these evaluations, requirements for a novel flight management system (FMS) function, which is set to be developed in the next steps of the project, were derived to support pilots and controllers through extended information exchange, thus increasing predictability of the lateral and vertical flight profiles for both sides. A central component is a novel airborne energy management assistance system including a configuration management functionality, to be implemented through an extension of the FMS capabilities.

Keywords Flight procedures · ATC instructions · Dynamic aircraft configuration · Energy management · Noise and fuel reduction

List of symbols

$L_{as,max}$ Max. A-weighted sound level, dB
 L_{AE} A-weighted sound exposure level, dB

ATC	Air traffic control
ATCO	Air traffic control operator
CDA	Continuous descent approach
LDLP	Low drag low power
TMA	Terminal manoeuvring area
FAA	Federal aviation administration
DLR	German aerospace center
DFS	German air traffic control organization
GD	Green dot speed
LG	Landing gear
SB	Speed brakes
F-x	Flaps position (1,2,3 or F)
VLS	Lowest selectable airspeed

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OSNEM	Final approach fix point for runway 14 in Zurich
ANSP	Air navigation service provider
DYNCAT	Dynamic configuration adjustment in the TMA
SESAR	Single European sky ATM research
ICAO	International civil aviation organization
ATRA	Advanced technology research aircraft
FMS	Flight management system

1 Introduction

Within the European Union's Horizon 2020 research and innovation programme under grant agreement No. 893568, the German Aerospace Center (DLR) together with Empa, SkyLab, THALES, and Swiss Airlines is participating in the project Dynamic Configuration Adjustment in the TMA (DYNCAT). This project aims at enabling more environmentally friendly approach profiles through novel pilot support functions.

Optimal on-board energy management requires precise flying of vertical approach profiles for which little guidance is available: the pilot has to decide, in compliance with ATC requirements, when to reduce speed, to set high-lift devices and to extend the landing gear to reach the approach speed at the stabilisation altitude. Large differences exist even between flights employing the same nominal procedures with identical initial conditions and comparable atmospheric states. This is due to the fact that under certain circumstances, the pilots receive instructions from ATC which can only be realised through early extension of the landing gear, increasing aerodynamic drag to reduce the excess of energy. Obviously, there is a huge potential to avoid unnecessary aircraft noise impact on the ground by shifting the extension of high-lift devices and landing gear closer to the runway with more appropriate procedures and optimised energy management. However, within the complex framework of today's airspace structures and traffic density and especially in different boundary conditions (e.g., wind and

aircraft mass), the implementation of an approach that is as fuel-efficient, low in CO₂ emissions and energy-optimised as possible (zero fuel waste) is a major challenge for the flight crew.

Pilots and state-of-the-art pilot assistance systems often do not have sufficient access to information necessary for planning and conducting an optimal approach minimizing fuel burn and noise impact [1–3]. This includes, for instance, detailed information about the expected flight plan, i.e., the vertical, lateral, and speed profiles planned by Air Traffic Control (ATC). Detailed meteorological information, such as wind and temperature profiles along the flight path are also not available nowadays. To propose a solution which not only accounts for all the information required for an optimized approach, but also considers the requirements of all stakeholders in the complex Terminal Manoeuvring Area (TMA) ecosystem, a critical analysis of the current situation has been performed in an exemplary way [4]. Furthermore, Workshops were held and interviews conducted to better understand the current limitations and capabilities of pilots and air traffic controllers in their daily work, as well as their demands for future systems and concepts developed over short- or mid-to-long-term. The results of this analysis are the subject of this paper.

1.1 Source data

To allow the influence of all current operational factors on the environmental impact in the TMA to be taken into account, a comprehensive data base, detailed in Fig. 1, is available to the DYNCAT project consortium. Prior to the analysis, the raw data from each available flight was combined into a data set and anonymized to protect the pilot's privacy. In total, 638 approaches to runway 14 at Zurich airport are available and representing a broad variety of operational and weather conditions, all of which were conducted with aircraft of type A320–214. The Airbus A320–214 has been used as reference aircraft type and Zurich airport as reference airport, representing a very common aircraft type and a busy commercial airport with a complex airspace

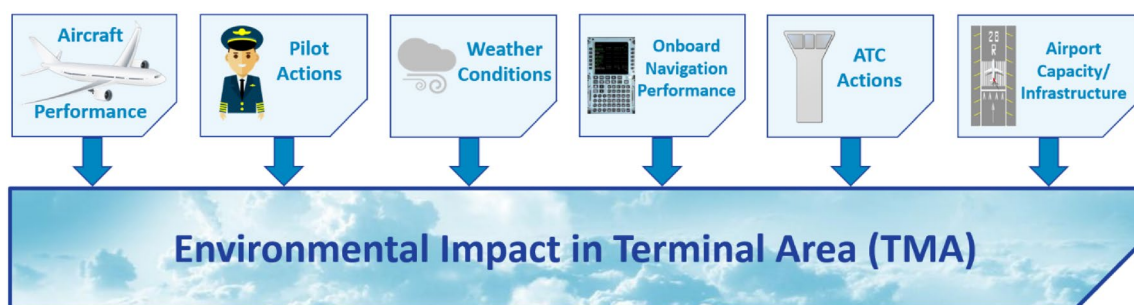


Fig. 1 Database for analysis of current operations (©DLR)

structure. The approaches were selected from the period between August and November 2019 to present a pre-pandemic traffic situation and are distributed proportionally relative to the real traffic density at this time. Each data set contains:

- Operational flight data
- Meteorological data
- ATC communication data
- Radar data
- Acoustical measurement data

The operational flight data contains information recorded by the aircraft itself. It gives insight into the general flight state (altitude, heading, speed, position, wind, etc.), active auto-pilot modes, and the aircraft configuration (flaps, landing gear and speed brakes). The pilots' energy management strategy, their reaction to external events such as ATC instructions, and the resulting engine thrust and fuel consumption can be derived from this data. An example of flight data recorded during an approach is shown in Fig. 11.

The meteorological data consists of weather data (e.g., wind, humidity, visibility, precipitation) recorded at one measurement station near Zurich airport. It can provide hints to help understand the choices made by pilots and ATC, e.g., related to low visibility or very windy conditions. It will also be used in subsequent project phases for detailed noise propagation simulations performed by project participant Empa.

The ATC communication data, which was transcribed from audio recordings prior to analysis, includes the radio channels of the approach controllers east and west of Zurich airport. It contains ATC instructions related to the approach planning (e.g., lateral/vertical guidance, speed constraints, and expected distance until touchdown). This information is crucial for understanding the interactions of all stakeholders involved in operations in the TMA. The distribution of all ATC communications per flight as well as its breakdown in speed, lateral, and vertical instructions can be seen in Fig. 2. In the upper left plot, it can be seen that a large number of flights perform descent and approach phases under frequent communication with the arrival controller; for instance, 82 flights have nine communications received from ATC. With respect to speed restrictions, as can be seen in the upper right plot, there is a significant number of flights that receive no speed instruction, about 85 flights. On the other hand, the maximum number of speed instructions found in the ATC communications for a single approach was eight. The lower left plot shows the distribution of the number of lateral instructions. Very few flights have no lateral instruction (3%), whereas the majority of flights receive at least three lateral instructions. The same picture can be seen on the lower right plot, where three or more vertical instructions

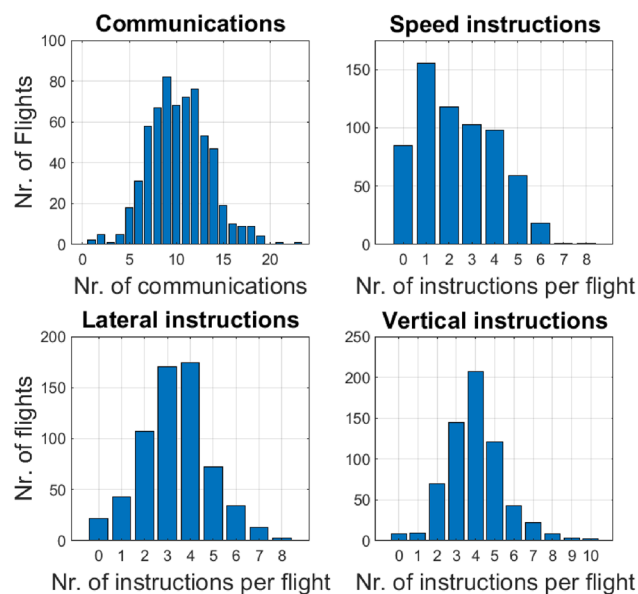


Fig. 2 ATC communication statistics

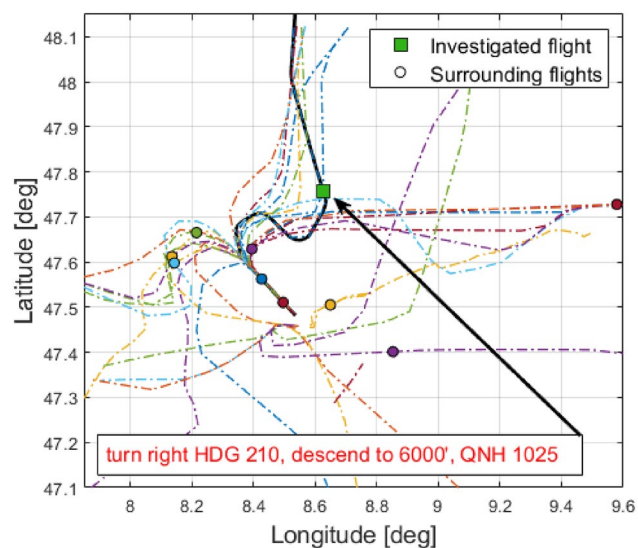


Fig. 3 Local traffic of flight in Fig. 4

are standard for the investigated flights. Combined with the lateral, vertical and speed profiles from the flight data, the pilots' implementation of ATC instructions can be investigated in detail (Fig. 4).

Radar data contains not only the flight track of the investigated flight itself, but also the surrounding traffic in the airport area at the time. This information helps assess the general traffic situation and understand the ATC decision-making process and intent, e.g., in a high traffic situation. Figure 3 illustrates a sample of a lateral flight path including the surrounding traffic.

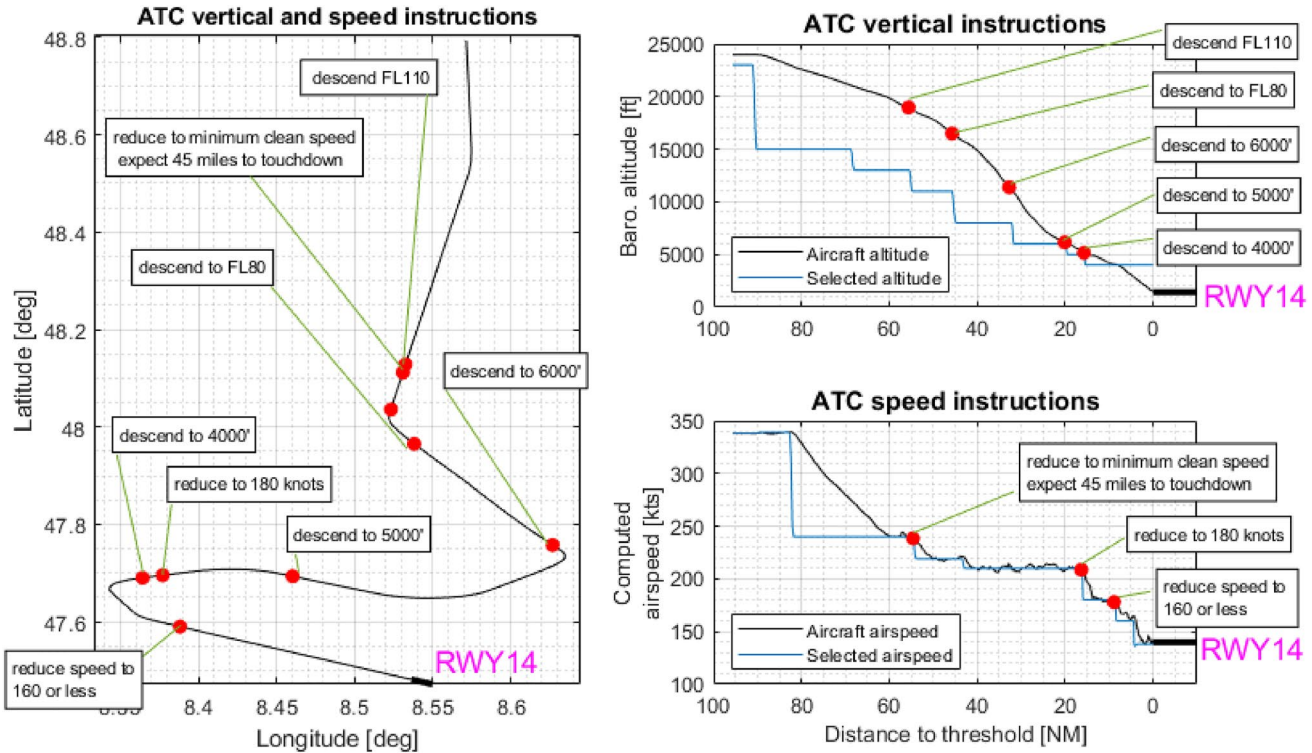


Fig. 4 Overview of investigated flight approach profile

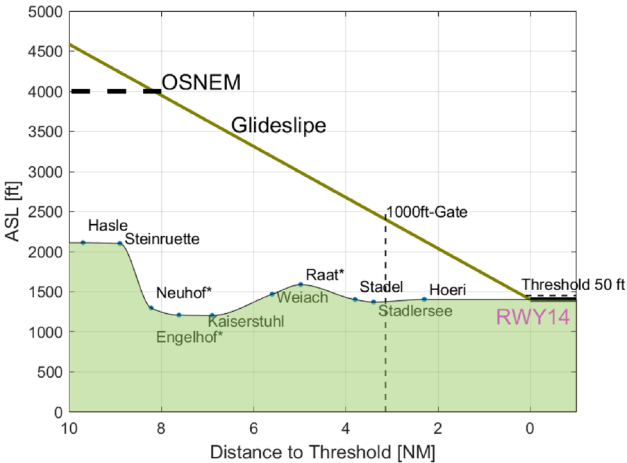


Fig. 5 Noise measurement stations located below the glide path

Acoustical measurements were performed by Empa over the course of a week, from September 9th to 13th 2019, at seven measurement points below the glide path (see Fig. 5). The resulting data set includes 1372 measured events corresponding to the regular operations of A320–214 aircraft, and is used to directly assess the noise impact of different energy dissipation strategies. In addition, to enable assessments outside of the specific measured locations below the glide

path, noise maps showing acoustic footprints of individual flights will be generated in a later project phase using the aircraft noise simulation tool *sonAIR* [5, 6]. *sonAIR*'s ability to accurately reproduce the noise exposure of individual flights had previously been proven based on data of public noise monitoring terminals [7]. A set of 70 approaches using the DLR's A320–ATRA, measured over the course of a week during a predecessor project of DYN-CAT, was used for validation purposes, yielding an average standard deviation of 0.9 dB between measured and simulated A-weighted sound exposure level [8].

For daily operations, ATC ensures safe separation between all flights inbound to a certain airport. To apply international safety rules to the local traffic management, the ATCOs provide each flight with arrival information and, if necessary, impose certain constraints on the pilots. Pre-defined lateral, vertical or speed profiles for arriving flights are, therefore, already common practice in some airports. However, if an optimization of the approach profile with respect to fuel burn and noise exposure is also pursued, additional information must be provided to the ATC controllers and to the pilots to allow them to manage this new scenario. It must also be taken into account that an ATC controller's decisions are often based on years of experience instead of static processes. This makes it complex to support their work with software algorithms.

To derive what kind of information should be included in a new FMS function, a critical analysis of the current operations at Zurich airport and the interaction between pilots and ATC was performed. The opportunities to enable more environmentally friendly approaches using this function, considering all involved factors (pilot actions, aircraft specifications, ATC, surrounding traffic, weather and airport capacity), will be presented.

2 Critical analysis of operations at Zurich

The basis for the concept of the novel DYNCAT function was to cluster the data according to speed instructions given by the ATC arrival controller. The evaluation of these data clusters is presented in Sect. 2.1. Furthermore, a selected set of approaches was investigated taking into account lateral and vertical instructions due to traffic. An example of these investigations is described by means of a comparison between two similar flights in Sect. 2.2. The analysis of all data sets, comprising different energy dissipation strategies, showed that approximately 92.5 % of the approaches were performed in a Continuous Descent Approach (CDA) profile. An ICAO definition of CDA procedures was used to identify them. This definition allows approaches containing level segments of up to 2.5 NM below 6000 ft to be considered as CDA [9]. Only 6 % were performed using the so-called Low Drag Low Power (LDLP) approach profile while containing level segments greater than 2.5 NM below 6000 ft, and 1.5 % were flights with glideslope intercept from above. 12.5 % of the flights included holding patterns and were excluded after the separation in speed clusters to avoid offsets in the evaluations (higher remaining track miles at low altitudes). Consequently, by comparing numerical results, it can be assumed that all incoming flights have similar approach profiles. Nevertheless, all flights, including the holding flights, were evaluated in terms of the statistics of ATC instructions.

2.1 Evaluation of speed restrictions

The ATC speed instructions were separated into the standard speed constraints given at Zurich airport by the approach controller. These constraints are usually the minimum clean airspeed, 180 kts, or 160 kts. The minimum clean speed, also called Green Dot (GD) speed for the A320, is an estimate of the speed for best lift-to-drag ratio in clean configuration, and is often used to allow arriving flights to operate in an optimum condition [10].

The speed constraints selected for the evaluations were verified by an analysis of the speed distribution at OSNEM, which is the final approach fix point (also called glideslope intercept point) for runway 14 at Zurich airport. These

selected constraints were additionally confirmed by the ATC experts involved in the project. At OSNEM, approximately 40 % of the flights are between 175 kts and 185 kts and 20 % are between 155 kts and 165 kts. This distribution is in line with the expected instructions.

The overall groups identified from all investigated flights are shown in Fig. 6. Each block shows the speed instruction as an underlined category name and the number of flights within that group. If one of the standard speed instructions, for instance 180 kts, was not given to a certain flight by ATC, that flight is placed (in this example) in the category branch 'No 180 kts'.

For the analysis and subsequent separation of flights with specific speed instructions from ATC, recordings from the approach controller frequency were available. Some of the data sets used in this work included flights which were handed over to the final approach frequency, for which no recordings were available. This is also the case for communications made outside of the TMA, e.g., between the crew and the enroute radar controller. Both communication links provide additional speed, lateral or vertical instructions for the flight crew which could not be included in the analysis presented here. For this reason, some assumptions had to be made regarding the speed of some selected incoming flights. It was observed that some incoming flights arrived in the TMA with a reduced speed, in the vicinity of the minimum clean airspeed. Therefore, it was assumed that, based on the speed distribution at approximately 30 NM, all flights with an airspeed near their minimum clean speed (which can be approximated using the aircraft mass and is a common speed

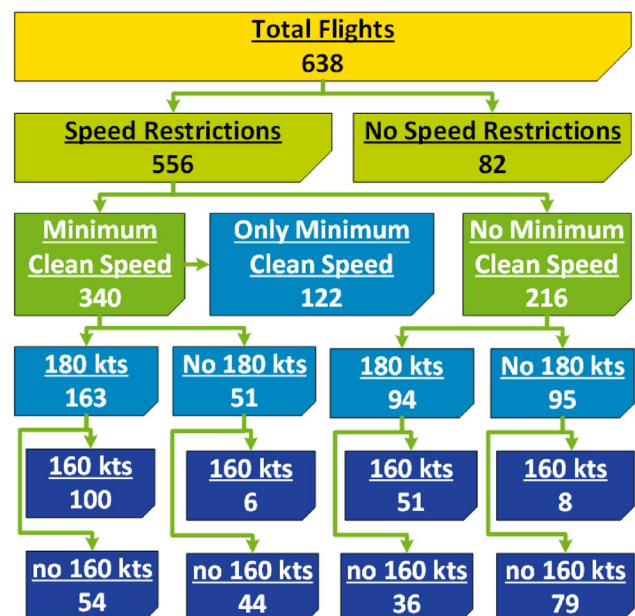


Fig. 6 ATC speed restriction overview. Note that some flights belong to categories not displayed in the graphic

constraint given at Zurich) belong to the group of flights with minimum clean airspeed instructed, although this could not directly be extracted from the data. This assumption was also validated by ATC controllers and pilots during the interdisciplinary meetings.

For each of the groups generated based on the speed instructions, an extended assessment of the flights is performed to evaluate the fuel consumption, noise exposure, energy management, and configuration management. The remaining flown track miles (or distance-to-go) are used as reference for each comparison. Some gates were defined for these comparisons, including for instance the stabilization at 1000-ft-gate, the final approach fix, the FL100-gate, or the 30 NM distance-to-go gate. These defined gates allow for the direct comparison of flights arriving from different directions and different way-points. See for instance the distribution of all flights divided in two main categories (*SpeedRestriction* and *NoSpeedRestriction*), shown in Fig. 7.

The FL100-gate is a good reference for data evaluation, because not all crews receive information on remaining track miles to touchdown. For this reason, pilots often rely on a rule of thumb to judge the optimal current altitude with

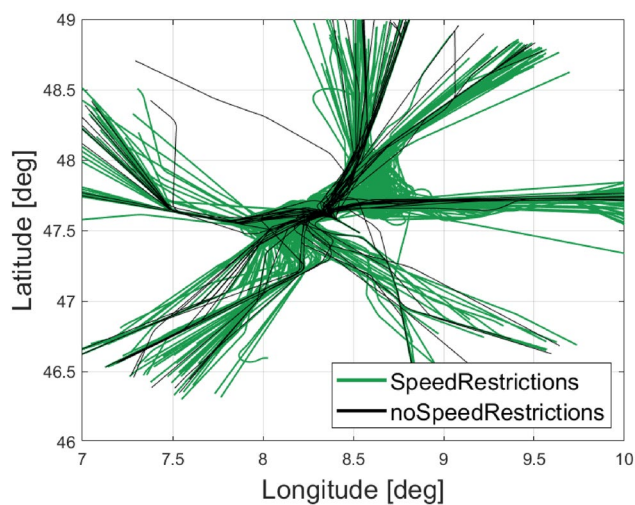


Fig. 7 Comparison of the lateral flight paths in the TMA until touchdown between flights having received at least one speed instruction and flights with no speed restrictions

regards to the estimated or given distance-to-go until touchdown. Therefore, it is assumed that descending through FL100 corresponds approximately to a distance-to-go of 30 NM to touchdown. This facilitates energy management, especially when no ATC restrictions are given.

The comparison of the two main groups of flights (*SpeedRestrictions* and *noSpeedRestrictions*) shows that flights without any speed constraints have a more direct lateral approach profile than flights with speed instructions, especially looking at the upper right portion of Fig. 7. These direct approach paths are reflected in the fuel consumed from FL100 to touchdown, where the flights without speed restriction consume approximately 50 kg less fuel than the speed-constrained flights. Even though, on average, unconstrained flights only have approximately 2 NM fewer flown track miles than the constrained flights (33.4 NM against 35.45 NM), the specific fuel consumption (kg consumed per remaining track miles) between the two categories is 4.40 kg/NM against 5.54 kg/NM, indicating a significantly lower fuel consumption for the *noSpeedRestriction* flights.

It should be noted that the evaluations shown in this work focus on the TMA. Therefore, if, for instance, a lower fuel consumption was evaluated due to a higher speed level in the TMA, this does not consider the potentially higher fuel consumption such a flight profile might have had during the inbound cruise flight up to the initial approach (FL above FL100). Evaluations from 'end-to-end' are not pursued in this project.

Tables 1 and 2 show the results for some selected representative categories of speed restrictions in terms of fuel consumption, flown track miles, time from FL100-gate to touchdown, and the specific fuel consumption based on flown track miles. It can be observed in Table 2 that even from the final approach point OSNEM to touchdown there is a significant impact in fuel consumption between some categories. For instance, fuel burn for flights with no speed restriction is approximately 10 % less than for those in the minimum clean speed category. The 1000-ft-gate was used to evaluate the difference between the current flown airspeed and $V_{APP,target}$, which is the approach speed target for the landing. This difference gives a good indication as to how stabilized the aircraft is for landing. It was observed that

Table 1 Results from FL100 to touchdown

Category	Fuel consumed in kg	Track Miles in NM	Time in s	Specific fuel burn in kg/NM
NoSpeedRestrictions	147	33.4	510	4.40
MinimumCleanSpeed	219	36.6	633	5.98
only MinimumCleanSpeed	212	35.9	624	5.90
no MinimumCleanSpeed	168	34.1	550	4.93

Table 2 Fuel burn results from OSNEM to touchdown (8 NM on the glideslope segment)

Category	Fuel consumed in kg
NoSpeedRestrictions	71.0
MinimumCleanSpeed	80.4
only MinimumCleanSpeed	79.8
no MinimumCleanSpeed	75.1
MinClean→ 180	80.9
MinClean→ 180 → 160	82.1
MinClean→ 180 → no 160	81.1
no MinClean→ 180	76.6
no MinClean→ 180 → 160	79.8
any other speed instruction	76.3

flights with speed restrictions had smaller deviations from $V_{APP,target}$ than flights with unrestricted speed management. For the selected categories of Table 1, the results were as follows: *NoSpeedRestrictions* flights had 83 % of flights with a deviation lower than 10 kts between current airspeed and $V_{APP,target}$. For *MinimumCleanSpeed* this share of flights was 94 %, for *onlyMinimumCleanSpeed* 92 %, and for flights in the category *noMinimumCleanSpeed* (i.e., with any other speed instruction), 96 % had a deviation below 10 kts. This shows that speed instructions have a positive impact on speed stabilization for the final approach. This leads to fewer 'excess energy' conditions, which are an indication of less stabilized approach profiles.

Another important observation when comparing the flights with and without speed restrictions concerns aircraft configuration management and its impact on the noise. Here it became visible that speed constraints lead to an early Flaps-1 (F-1) deployment during the approach phase. This is not unusual, seeing as F-1 might be required to comply with a lower speed restriction, depending on the aircraft mass. In addition, the use of speed brakes is very limited when flying in clean configuration close to the minimum clean airspeed.

In this situation, the usage of speed brakes in clean configuration is limited when the aircraft is flying close to the minimum clean speed. However, to comply with the descent instructions, the deployment of speed brakes is necessary. As a consequence, the pilots have to extend F-1 early to achieve a sufficient margin from the actual speed to the lowest selectable speed (VLS) and to stay within the speed limits when using speed brakes to decelerate further or effectively descend if additional ATC instructions are provided. This is probably the type of reasoning that results in the early use of the F-1 configuration, which can be seen in Fig. 8. This contributes significantly to the noise foot print of the arriving flights.

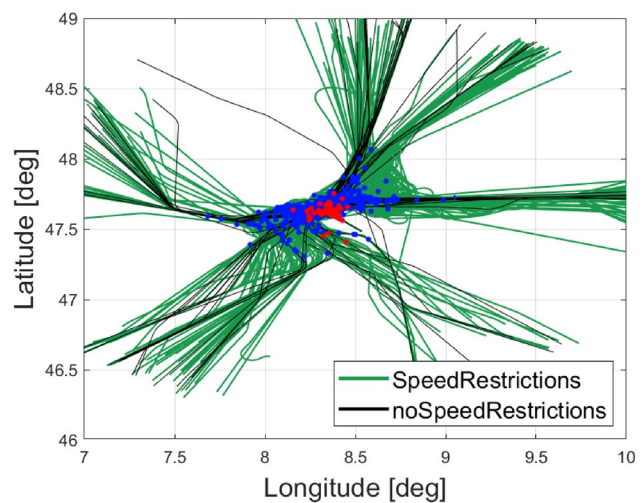


Fig. 8 F-1 deployment point of both selected categories. Blue markers for the SpeedRestriction flights and red markers for the NoSpeedRestriction flights

Noise exposure assessment was performed based on the $L_{as,max}$ and L_{AE} values at each noise measurement station for several of the groups of Fig. 6. Unfortunately, very small differences between the noise exposures of the groups were observed. This is not unexpected, considering the noise measurement stations are located below the glideslope after the final approach fix point, where the majority of the flights are already configured in F-1 or F-2. Nevertheless, it was observed while comparing groups of flights, e.g., *NoSpeedRestriction* against *SpeedRestriction*, that the usage of the landing gear (LG) at higher speeds, see Fig. 9, might be a contributing factor for higher noise exposure. This appears as a difference of approximately 1 dB $L_{as,max}$ at the noise measurement stations Kaiserstuhl,

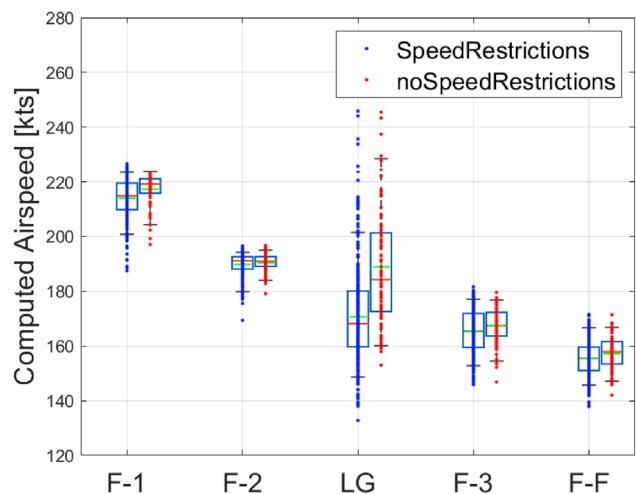


Fig. 9 Configuration set up as function of airspeed

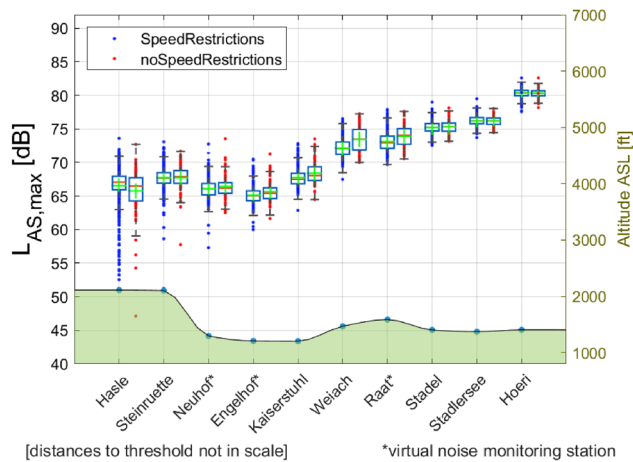


Fig. 10 Comparison of the $L_{AS,max}$ results for each noise measurement station of the *SpeedRestriction* and *NoSpeedRestriction* categories

Weiach and Raat, see for instance Fig. 10. The next steps of this project, which are currently ongoing, will include extended assessments of the noise exposure of some selected groups of flights.

2.2 Evaluation under traffic influence

In the previous section, the evaluations included only the speed instructions given by ATC. For a detailed assessment of the ATC instructions and their environmental impact, the traffic situation during an investigated flight must be included. The next example demonstrates the capability to perform such evaluations developed within this project (Fig. 11).

Figure 12 shows two flights with similar ATC speed instructions which, however, assume different approach profiles due to traffic and/or additional ATC vertical instructions. As shown in the top left plot of Fig. 12, both flights are at the same speed level between 40 NM and 20 NM due to the minimum clean airspeed constraint imposed by ATC. While flight #250 is instructed early to descend to FL080, which it rapidly accomplishes using speed brakes and F-1 configuration, flight #583 is only cleared to descend from its current FL150 later and in steps (T-3 and T-5 in Fig. 13). The reason for these two very different vertical instruction strategies adopted by ATC can be seen in the traffic data. Flight #583 is initially blocked from descending further by a 58 t category flight, as can be seen in T-1 to T-3 in Fig. 13. For flight #250, see Fig. 14, no explicit reason could be found for the early descent instruction given by ATC. Flight #250 is clearly the last flight in the sequence for landing at runway 14, and the instruction for an early descent led to a shallow flight path over the last 20 NM. This inevitably entailed an increased engine regime and consequently higher fuel

consumption. In precisely this kind of approach scenario, the novel function pursued in the DYN-CAT project shall provide the flight crew as well as the ATC controllers with additional information to allow environmentally friendly and optimized approaches.

3 Conclusions and outlook

Virtually all real-life approaches deviate from the theoretically possible in terms of noise and fuel consumption minimisation under the respective circumstances. This may on one hand be due to operational necessities from ATC (e.g., airspace structure, separation requirements), but there are also many suboptimal situations which are only a consequence of lack of information: on ATC intentions including the expected distance-to-go (DTG) and the wind situation along the approach profile on board, and on the specific aircraft's capabilities and limitations as well as the wind situation in the TMA on ground. In addition, there is insufficient systems support in trajectory and flight state prediction on the flight deck, so that pilots tend to implement approaches more conservatively with unfavourable consequences on noise and fuel consumption. This includes the configuration setting, speed management, use of speed brakes. It should be noted at this point that this problem is not due to an inadequate qualification of pilots. ATC speed instructions related to the vertical, lateral and speed profiles and the weather conditions have been shown to have an impact on fuel consumption, see Sect. 2, as well as on the noise footprint of approaching flights at Zurich, Fig. 8. It was observed that flights with fewer speed restrictions showed more direct flight paths to final approach. These flights show a lower fuel consumption, mainly due to higher speeds and longer portions of the flight spent in IDLE engine regime. The shorter distance to threshold shows only a minor effect on fuel consumption, which was confirmed by evaluating a specific fuel consumption (kg consumed per remaining track miles) for each category. However, it was also observed that fewer speed instructions led to higher overall speeds, landing gear deployment at higher speeds, and greater use of speed brakes to decelerate in the final approach phase, contributing to a higher noise exposure. If more speed instructions are given, especially when given very far from touchdown, they lead to higher fuel consumption, because the corresponding flights need to maintain a certain speed constraint for a longer period of time with higher engine N1 levels. It was also observed that these speed restrictions often lead to early deployment of F-1 and F-2 configurations, which probably also contributes to a higher noise exposure. Evaluated from the final approach fix point, for instance OSNEM at Zurich, it was observed that speed

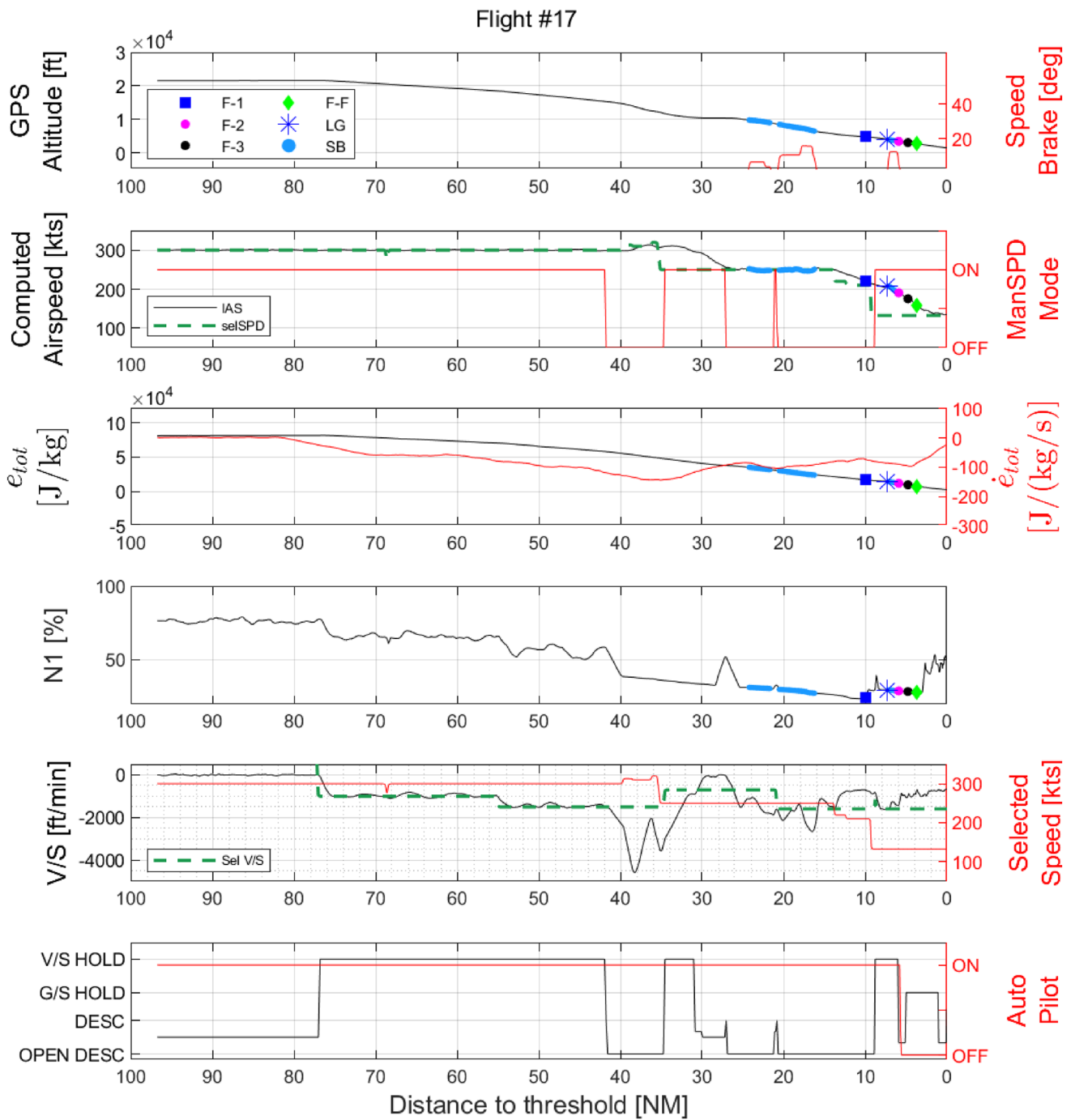


Fig. 11 Overview of operational flight data

restrictions given in the TMA even have an impact on fuel consumption in the last 8 NM. As was shown in Table 2, the lower speed levels resulting from the instructions lead to longer segments spent in non-idle engine regimes between OSNEM and touchdown. In addition, flights with more speed restrictions had smaller deviations from the required approach speed target at the 1000-ft-Gate, showing an influence on the stabilization rating. The evaluation

of the lateral instructions revealed that there is less influence of the level of traffic on the ATC instructions than expected. The main differences could be seen for those arrival routes in which there is more margin in the airspace available and consequently there is a higher variety in the ATC lateral instructions. In summary, it could be confirmed that the design of the airspace in the surrounding of the airport is the main driver for the number and type

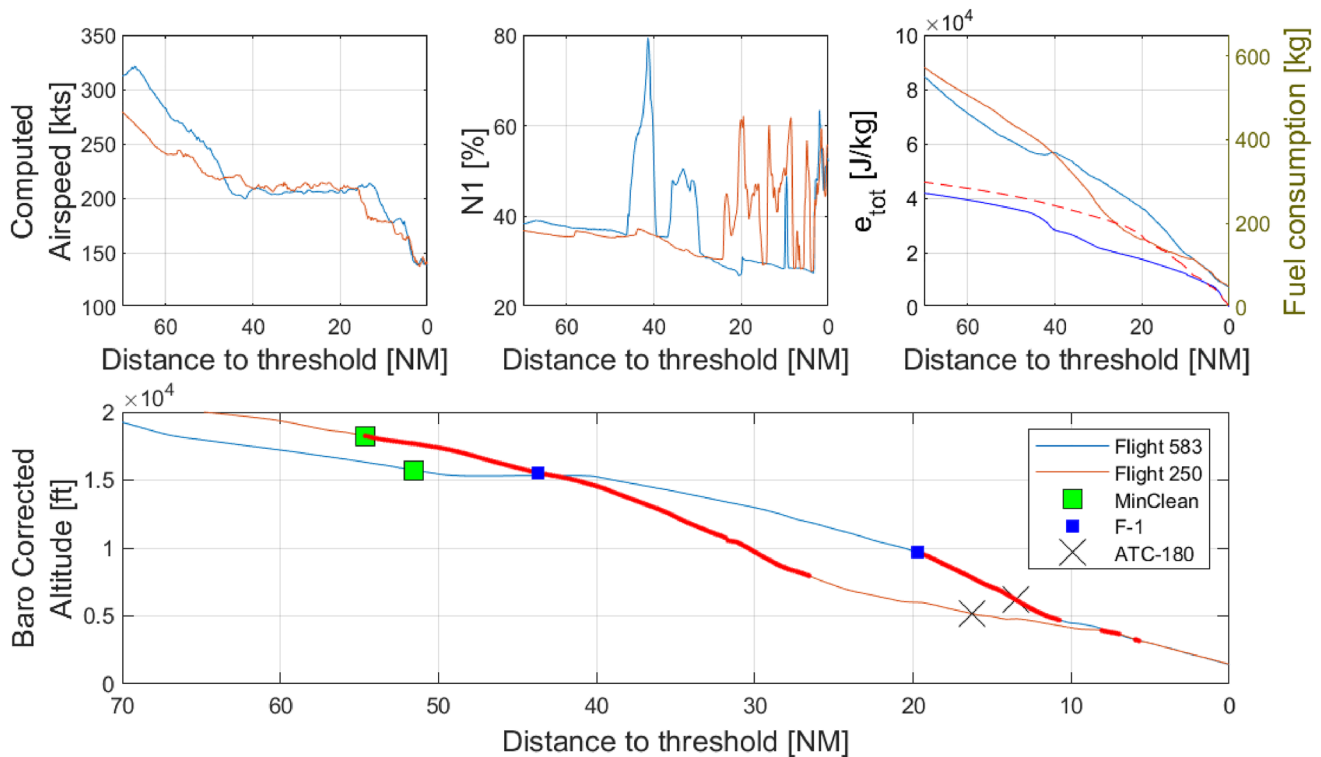


Fig. 12 Comparison of approach profiles of two flights with similar speed instructions

of lateral instructions. The detailed analysis of the vertical instructions revealed that different guidance strategies for the incoming flights are adopted, especially based on the arrival route. The most impacting factor leading to a higher fuel consumption is a precipitated instruction to descent to a lower flight level, which is not compatible with the aircraft's optimal approach procedure. In most cases this leads to a shallower approach during the last track miles or even to level flight segments, requiring the application of extra thrust. Furthermore, it could be identified that neither the actual wind conditions experienced by the aircraft nor the weather forecast have an influence on the ATC procedures and instructions. The impact of the presence of headwind components on increased fuel consumption could be clearly demonstrated and confirms the expected effects [4]. A potential for improvement would be the implementation of a datalink to share wind information of preceding aircraft with the following aircraft directly or via ATC to make the approach more predictable to the pilots or aircraft systems. This solution could also provide further information about vertical winds (thermals), which influence possible sink rates, or the presence of icing

conditions. The ability to analyse the ATC communications, aircraft information, noise measurements, weather data, and radar data together is unique and gives extended insights into current operations, allowing the identification of improvements for the reduction of their environmental impact. With a pilot assistance system providing an intuitive indication of the current energy status of the aircraft, taking into account the expected distance (e.g., dynamic transitions), time-over-target for the FAP, the wind information and an intuitive visualisation derived from this, a sustainable contribution could be made in the short term for more economical and ecological approaches. Further potential for improvement concerns the way ATC instructions are issued. Typically airspeed, altitude and heading instructions must be applied immediately by the flight crews. The lack of information for them regarding the exact time of the next altitude or airspeed instruction leads to unnecessary conservative approaches, which might already be mitigated by instruction tolerances where possible, especially with regard to the airspeed (e.g., "minimum 180 kts" instead of "reduce 180 kts") or the time of leaving an intermediate altitude (e.g., "when ready descent

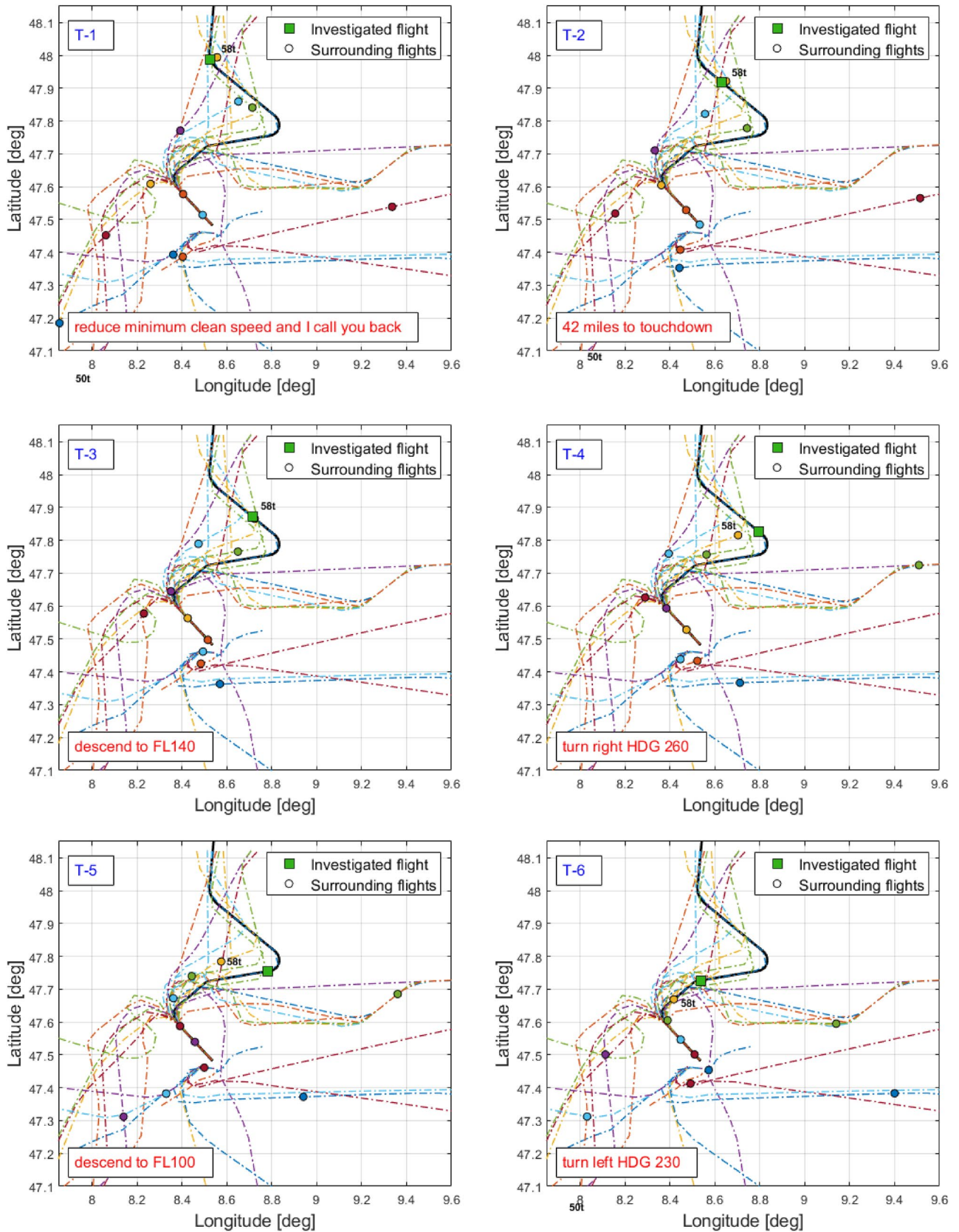


Fig. 13 Selected timestamps of traffic surrounding flight #583

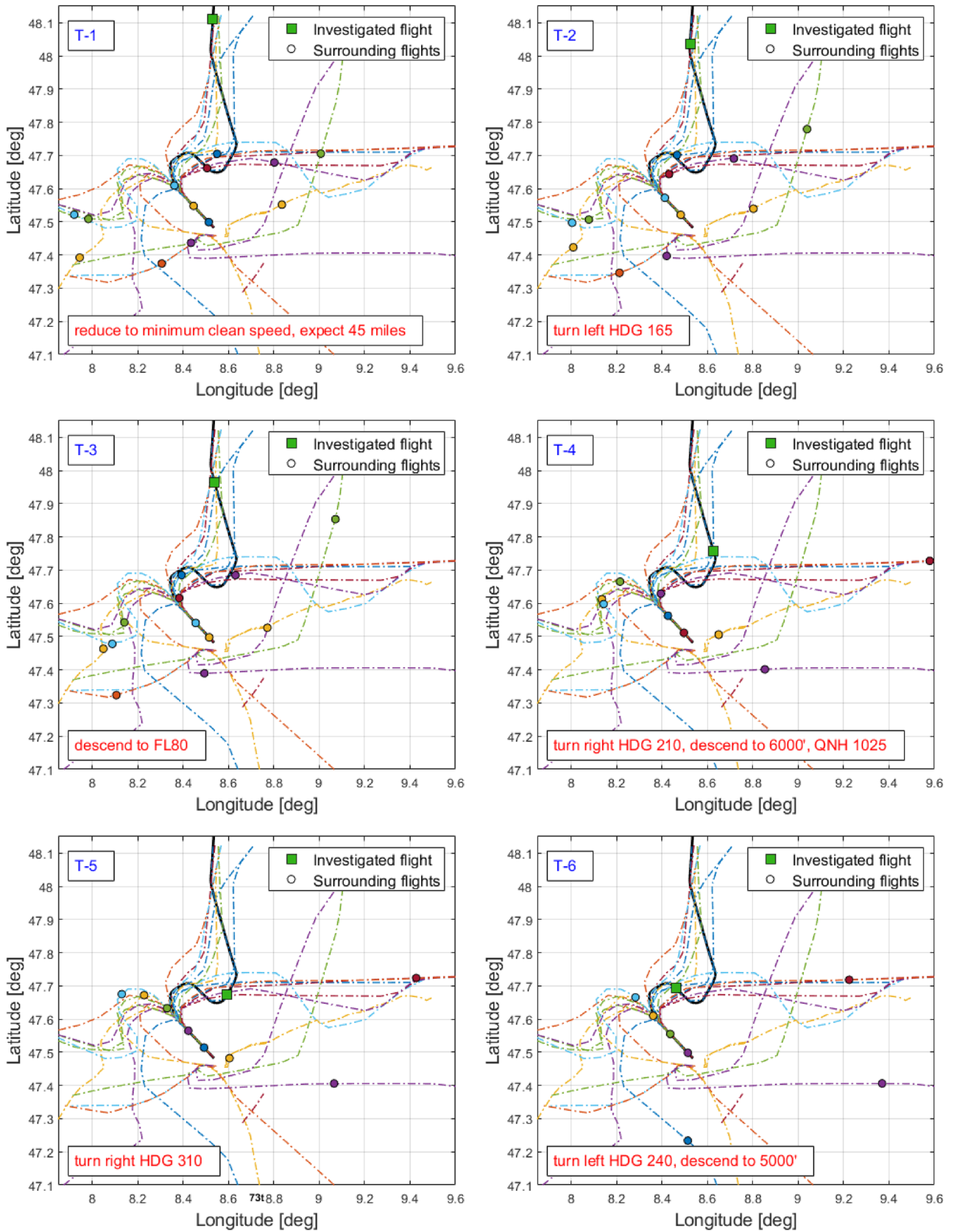


Fig. 14 Selected timestamps of traffic surrounding flight #250

FL 70” instead of “descent FL 70”). This would not only allow to fly closer to the optimum aerodynamic conditions of the aircraft type at its current weight, but could help to avoid thrust-intensive short level segments until the next clearance is given.

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