



**THE IMPACT OF FUEL BASED SPEED REDUCTIONS
ON CONTROLLER CONFLICTS IN THE
NATIONAL AIRSPACE SYSTEM**

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This report is based on the Master's Thesis of Heiko Udluft in partial fulfillment of the requirements for the degree of Master of Science at the Technische Universität Darmstadt.

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by

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Abstract

Motivated by increasing fuel prices and a higher environmental awareness, a reduction in aircraft cruise speed leads to fuel-burn benefits. However such a change will likely not occur simultaneously fleet wide. Thus, it is likely that in future scenarios the variation of speeds flown in the National Airspace System (NAS) will increase and lead to a higher system complexity.

The objective of this study is to investigate the effects of reduced aircraft cruise speed on the NAS. Using the airspace simulation tool FACET a set of scenarios has been simulated to determine how a reduction of cruise speed will impact the number of conflicts that occur in the NAS.

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AAL American Airlines

API application programming interface

ATC Air Traffic Control

DAL Delta Airlines

ETMS Enhanced Traffic Management System

FACET Future ATM Concepts Evaluation Tool

FAA Federal Aviation Administration

GUI graphical user interface

MAP Monitor Alert Parameter

NAS National Airspace System

NASA National Aeronautics and Space Administration

NextGen Next Generation Air Transportation System

RNAV Area navigation

RNP Required Navigation Performance

US United States

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Chapter 1

Introduction

1.1 Motivation

Fuel burn of air transportation is becoming more important, and fuel prices and environmental awareness are expected to further increase in the future. Two different approaches show that in the future air transportation system cruise speeds might be reduced. One approach demonstrates that in order to reduce fuel burn, future aircraft are expected to be designed for a lower cruise speed (see chapter 1.1.1). Another study by Lovegren showed that today's aircraft are currently not operated at their fuel burn optimal speed and altitude profile. Optimizing aircraft altitude and speed could reduce the "total system-wide fuel burn" during cruise by 3.48% [1]. These savings can be an incentive for an airline as to reduce fuelburn and cost.

For a change in cruise speed, the stepwise deployment of new technologies that is expected in the Next Generation Air Transportation System (NextGen) initiative implies that there will be a higher mix of cruise speeds in the system. The higher mix in cruise speeds will increase the ATC complexity (see chapter 1.1.2). It is assumed that a reduction of cruise speeds will have a system wide impact on the number of conflicts occurring in the National Airspace System (NAS). As discussed in chapter 1.1.2, an increase in the number of conflicts is likely to impact the controller workload.

For this study, the number of conflicts occurring in the NAS was chosen to investigate the effect of a change in aircraft cruise speed on controller workload.

1.1.1 Magnitude and Impact of Speed Changes

According to preliminary results of a study on potential future aircraft design undertaken by Juan J. Alonso et al.¹, potential future aircraft are expected to be designed for a reduced cruise speed motivated by the resulting fuel burn benefits. Preliminary results of the work indicate a reduction of cruise speeds between 6% and 10% compared to today's aircraft. For this study, a reduction of 8% in cruise speed is assumed for future aircraft and is investigated in simulations in chapter 3.

Reduced aircraft speed changes are expected to have an effect on the NAS. Specially, since the speed changes are likely to occur incrementally, the variation of speeds flown in the NAS is expected to increase, as some aircraft will fly reduced speeds, while others will still be flying current speeds.

It is expected that the speed change has an influence on the number of conflicts occurring in the NAS. This has an influence on the controller workload, as a conflict has to be resolved by controller interventions, as discussed in chapter 1.1.2.

1.1.2 ATC Complexity and Controller Workload

Different definitions of complexity in the NAS can be found in literature. Athenes et al. state that "ATC complexity is subjectively defined by the controller", and finds that it "accounts for a large proportion of controller workload" and that "it is reasonable to assume that as ATC complexity increases, controller workload increases".[2]

Airspace complexity is often referred to as "Dynamic Density"[3]. Laudeman et al. [4] defined a dynamic density equation using eight "air traffic complexity factors", which include, predicted conflicts, the minimum distance between aircraft, as well as speed, heading and altitude changes.

Buckley et al. noted that "confliction" has an influence on controller workload. [5]

As part of a "method for prediction of air traffic controllers's workload Catterji and Sridhar introduced the "variance of groundspeed" as measure for complexity.[6] As a

¹(personal communication)

reduction of aircraft cruise speed is unlikely to occur simultaneously throughout the system, it will increase the variance of groundspeed and thus the system complexity and the controller workload.

The capacity of today's ATC system is limited by the air traffic controller. [7] Thus an increase in ATC complexity and therefore controller workload could reduce the capacity of today's ATC system, which contradicts the requirement of NextGen system which is to increase the capacity of the ATC system [8].

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Chapter 2

Research Approach

In this Chapter, the general approach to the research problem and the simulation set-up to investigate the effects of aircraft cruise speed reductions on the NAS are described. At first, the available data sources and the data used for the simulations are introduced. The airspace simulation tool FACET, as well as improvements and additions made to the tool for this study, are described. The experimental setup for the simulations is introduced.

2.1 Data used for the analysis

The analysis presented in this thesis uses a simulation set up file that was provided, along with FACET, by the National Aeronautics and Space Administration (NASA). The file contains data for August 24th, 2005 for flights departing to and from the US. It was provided in FACET's proprietary TRX format. The data is based on data from the Enhanced Traffic Management System (ETMS). ETMS data, and as a result the simulation data, contains information about how a flight is intended to be operated, such as flight plan, departure time, arrival time and aircraft type, as well as how a flight was actually operated including recorded aircraft position (radar tracks) for each flight.

The data provided by NASA contains flight numbers, flight plans and initial positions and for 58,522 flights in 24 hours. Aircraft types in the ETMS data that are

not supported by FACET have been mapped to those that are supported.

2.2 Simulation Environment

To investigate the effect of a cruise speed reduction on the NAS, a simulation of the traffic in the NAS is conducted. The cruise speed reduction is applied to certain aircraft based on different scenarios that are discussed in chapter 2.4. The simulation returns as a result the number of conflicts that occurs. In this chapter the environment for this simulation is described and its capabilities discussed.

2.2.1 Introduction to FACET

The NASA tool FACET is used as the environment for the simulation of the effect of a cruise speed reduction on the NAS. FACET is "a simulation environment for exploration, development and evaluation of advanced Air Traffic Management concepts" [9]. FACET incorporates information for sectors, airports and navigational aids. It offers performance data for most common aircraft types and uses a model to compute flightpaths according to given performance data. FACET offers ways to track, visualize and export parameters of the NAS. It provides a GUI and an application programming interface (API) written in Java to interact with the simulation environment.

The FACET GUI

With the FACET GUI a simulation can be run and replayed based on a pre defined file containing flight plan data. The File format TRX is specific to FACET and contains the following data:

- Time
- Aircraft call-sign
- Position

- Altitude
- Speed
- Heading
- Vertical velocity
- Flight plan

When running a simulation, FACET shows all aircraft currently in flight on a map. Figure 2-1 shows a screenshot of what the FACET GUI looks like.

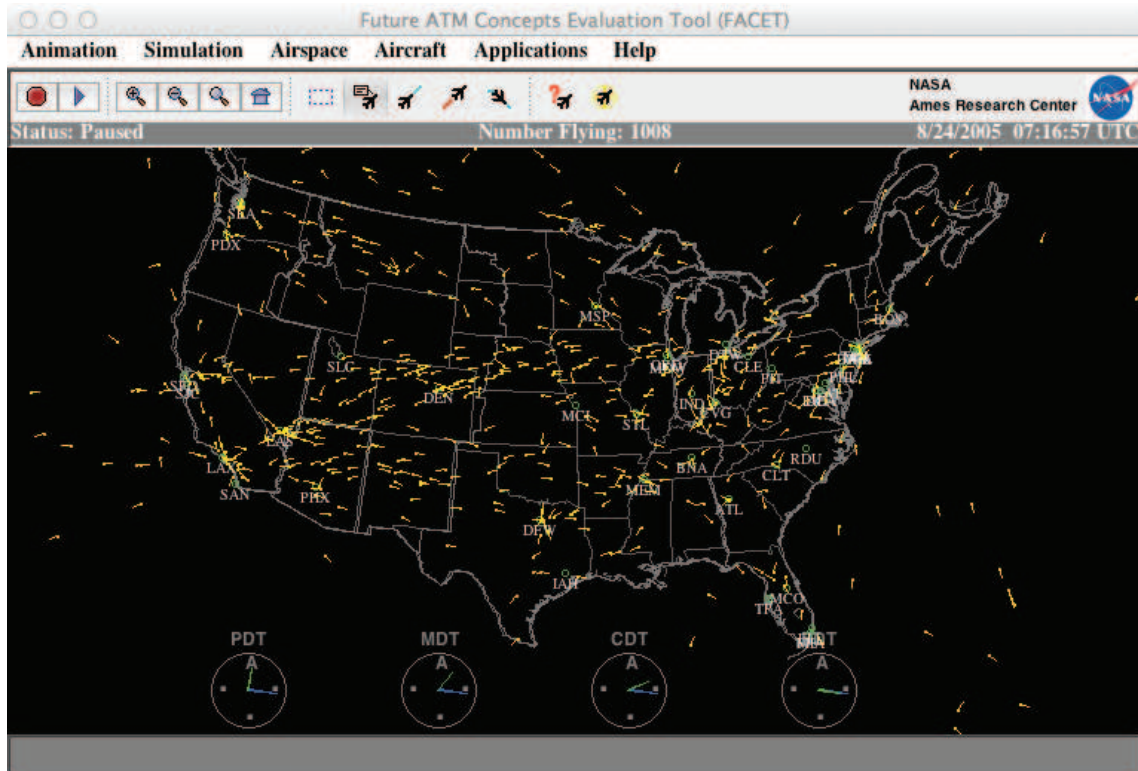


Figure 2-1: Screenshot of the FACET GUI

The positions of all aircraft currently flying in the simulation are displayed as a dot with a line indicating their heading. The window can be rotated and tilted to show 3D information. Sets of aircraft can be filtered and highlighted, for instance by departure airport or aircraft type, according to user needs. FACET also can display sectors and centers and plot a variety of information such as sector counts or current number of aircraft flying.

FACET's Application Programming Interface

The FACET API allows the users to expand the functionality of the the simulation environment. Using the Java language, most parameters of the simulation environment can be retrieved and modified through pre-defined interfaces. Using these interfaces, new modules can be written that expand the existing simulation environment. The API allows advanced users to tailor FACET to specific needs.

2.2.2 FACET Additions and Modifications

In order to run the simulations and retrieve data needed for this study, the functionality of FACET has to be expanded. For example FACET does not natively support ETMS data. To run simulations based on data from ETMS, an import / export functionality is added. The simulations in FACET are based on the proprietary TRX file format, where different parameters of a flight i.e. cruise altitude and flight plan are stored. The cruise Mach number however is determined based on aircraft specific performance data and cannot be changed directly. A workaround to alter the speeds in the simulation is developed. The changes to the airspeed are not to be made to the entire fleet, but to certain randomly selected percentages of aircraft. This filter is also implemented.

Change Speed of Aircraft Within the FACET Simulation

FACET allows changes to most parameters of a flight either through the information in the TRX file or the GUI. The speed however is calculated based on aircraft type specific performance data that is stored in encrypted files and can not be modified directly. The TRX file does contain speed information which is used when a previous simulation run is played back, but not when a new simulation is run. A workaround is implemented using the FACET API, that allows for setting the speed of an aircraft to a desired value. The speeds flown during climb and descent are calculated by FACET based on aircraft performance data.

During the climb and descent phase, FACET determines the speed flown for each

aircraft based on FACET's internal aircraft performance data. As soon as it reaches its pre defined cruise altitude and cruise speed, the speed is altered to the desired value.

Randomize Function to Select Aircraft for Cruise Speed Reduction in the Simulation

The simulations are run for different groups of aircraft. Within these groups the speed is to be changed to different percentages. A function that filters and randomly selects aircraft based on defined parameters is added to FACET. Picking random aircraft also allows the user to run multiple simulations using the same flight plan files. Since FACET generates the list of aircraft in the simulation at runtime, the aircraft with changed speed cannot be picked in advance. The function also checks to ensure that no aircraft is selected twice.

Expand FACET's Data Import

The intention to simulate representative real traffic scenarios motivates the use of data from ETMS, as it gives information of actual aircraft flight plans within the NAS that can be used as input for the simulations. A simulation based on real ETMS flight plan data will allow the comparison and verification of the results of the simulation to real recorded radar tracks. The data is available in ETMS format, which is not natively supported by FACET, so the ETMS data has to be transformed to a FACET compatible format. FACET uses a proprietary data format that contains data about both flight plans, as well as recorded aircraft positions. FACET stores its data in the TRX-file. FACET uses the TRX file to set up, record and playback simulations. A recorded simulation has multiple data points per flight according to the update rate of the simulation. In Playback mode, FACET replays a former simulation run. In simulation mode, FACET searches through the file for the next timestamp and adds new aircraft to the simulation. If multiple data point exist for a flight, the first data point is used to set up a flight the simulation run. To run a simulation, FACET requires the following information for each flight: - timestamp when flight is initiated

- aircraft type - aircraft callsign - initial position and speed of aircraft - commanded cruise altitude - flightpath way points

All this information is stored in an ETMS dataset, but spread over different files. The raw ETMS data is stored in .csv plain text format. The data needed to generate the simulation setup file for FACET is stored in different files of the ETMS dataset. In order to allow a fast and flexible processing of the ETMS data, as a first step it is stored in a MySQL database. The MySQL interface allows a direct .csv import. The interaction with the database is handled by PHP, which is also used to export data from MySQL and put it in a TRX file format. Inconsistencies in the ETMS data can lead to problems with the data conversion. FACET uses predefined performance data for simulation, which is not available for all aircraft types in the ETMS data. Unsupported aircraft types must be mapped to comparable aircraft types that are supported by FACET.

Expand FACET's Position Data Export

To use existing post processing tools, the FACET TRX file needs to be converted to a standard format. The FACET TRX file contains flight plan and 4D position data of all flights, which can be transformed to the ETMS format. FACET is set up to interface with a MySQL database, but does not allow a direct export. To read the TRX file into MySQL a PHP script is used to break up the TRX data into different parts of the same format as ETMS data. However, recording a simulation into a TRX file causes the simulation performance to drop. The TRX file contains redundant information about a flight. For example, the way-points of a flight plan are stored for each recorded position of a flight.

Instead of using the TRX export from FACET, the Java API was used to directly export position and flight plan data of the aircraft in the simulation. This method uses less space and has less influence on the computation performance. The exported position data was used to detect conflicts as described in chapter 2.2.3.

2.2.3 Improvement of FACET conflict detection

A simulation in FACET is iterated with a constant iteration step time selected by the user. In this work, the step time is chosen at 60 seconds. A small simulation step time allows for simulations with a high resolutions to capture the system dynamics, but comes at the cost of a high computation time.

For this study, a change in the number of conflicts due to a reduced aircraft cruise speed is evaluated. As FACET detects conflicts only on each iteration step time, a high iteration step time will lead to FACET missing conflicts. To understand this effect, figure 2-2 shows two different head on conflict situations.

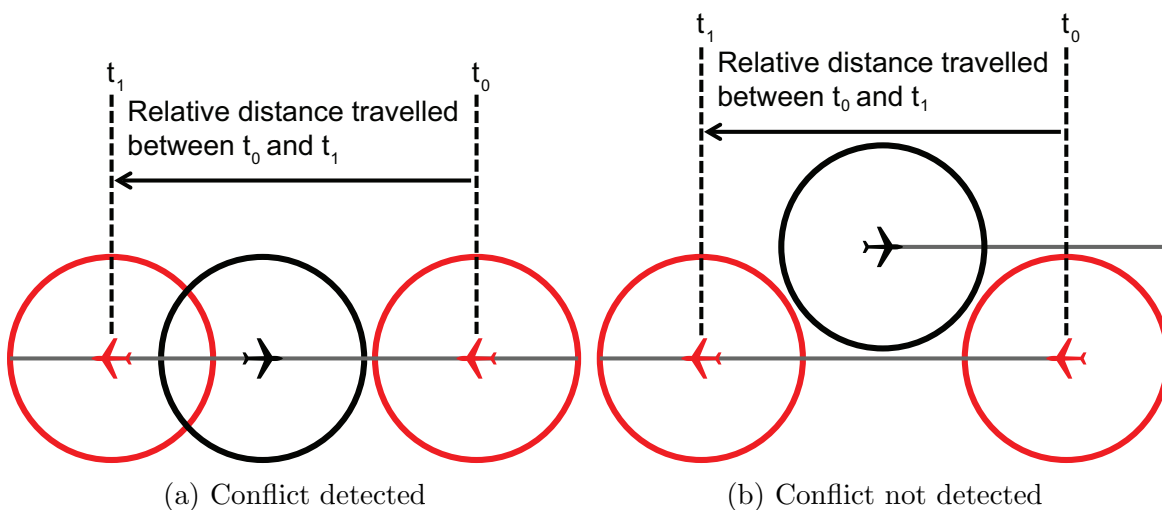


Figure 2-2: Different Conflict Situations in FACET's conflict recording

In figure 2-2a two aircraft are on the same flight path. At the first iteration step of the simulation the two aircraft are not in conflict. At the second iteration step the minimum horizontal separation is violated and the conflict is detected by FACET. The distance travelled between two iterations is smaller than the required minimum separation. In Figure 2-2b, the only difference to the previous situation is a shift of the aircraft flight paths. At the first and the second iteration step of the simulation the two aircraft are not in conflict. Between the two iteration steps however, the minimum horizontal separation is violated and the two aircraft are in

conflict. FACET does not record the conflict because it only looks for conflicts at every iteration step.

To assess the true number of conflicts, the simulation step time should be close to 0 seconds. However, reducing the simulation step time results in a significant increase in computation time for each simulation. At an iteration step time of 60s each simulation is computed in approximately 45 minutes. At an iteration step time of 1 second the computation of each simulation takes approximately 2 days. In addition, for a smaller iteration step time the post-processing of output data takes longer as well, as more data is recorded during the simulation.

Using MATLAB the conflict detection is improved while still using a 60 second iteration step time. Flight paths are interpolated with a resolution of 0.1 seconds to avoid not detecting conflicts. This is a big improvement to FACET's conflict detection that would track conflicts every 60 seconds. The time for post-processing is increased to about 3 hours per simulation run, which is a reasonable increase. As described in chapter 2.2.2 position data of is outputted. For each iteration, conflicts are detected in a three step process:

First the distances between all aircraft is calculated at the first timestep (t_0). All aircraft pairs at a distance below a search range are defined as potential conflicts and filtered for further analysis. This step does not differentiate between horizontal and vertical separation. As a second step, potential conflicts are filtered for an altitude difference between aircraft below the minimum vertical separation. As third step the flight path of aircraft is interpolated at 0.1s between t_0 and the next timestep (t_1) for each potential conflict and the distance of the two aircraft is calculated for each interpolation. Figure 2-3 illustrates this step by showing an example of two aircraft in a conflict.

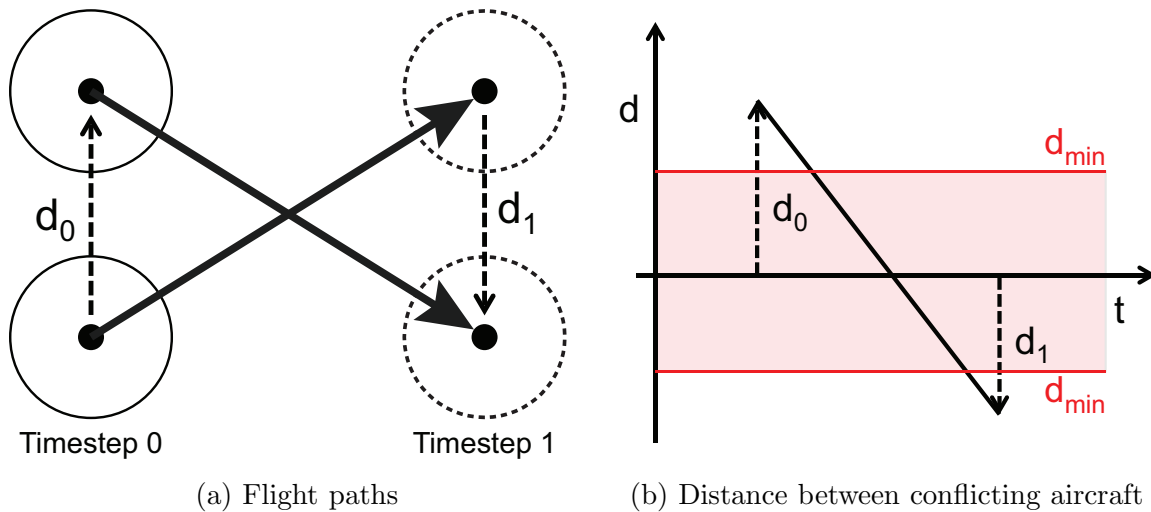


Figure 2-3: Improved conflict detection

FACET's conflict detection would not register this conflict as the distance d_0 at iteration step t_0 and the distance d_1 at iteration step t_1 are above the minimum horizontal separation d_{min} as illustrated in figure 2-3b. However, using the improved method, interpolating the flight paths of the aircraft and calculating the distance for each interpolation point shows that the minimum distance d_{min} is violated and the conflict is detected. For each conflict the following information is output to a file:

- Iteration step of the simulation (time)
- Minimum distance between aircraft
- Heading difference between aircraft
- Position, speed and altitude of both aircraft at t_0

Instead of using FACET's conflict detection where conflicts are tracked every 60 seconds, using this methodology conflicts are tracked at a significantly higher resolution of 0.1 seconds with a reasonable increase in computation time of about 3 hours.

2.3 Assumptions

To run the simulations of traffic within the NAS, certain assumptions and simplifications are made. It is assumed that a change of speeds flown in the NAS will have system wide effects and influence the controller workload. For the simulation, flight paths are simplified (see 2.3.1), conflicts between aircraft are not resolved (see 2.3.2) and weather influences, especially wind, are neglected (see 2.3.3).

2.3.1 Simplified Flight Path

Simulations in FACET can run in two different modes to model flight paths. In the "Direct Route" mode airplanes fly on great circle routes from origin to destination, which is the shortest path between these two points on the earth's surface. In "Flight Plan" mode, airplanes follow a set of way points which is defined in the setup file for the simulation. For this study, "Flight Plan" mode is used as it represents the way aircraft are currently operated. The flight paths specified by way points are ideal in the sense that simulated aircraft follow the specified path exactly. In reality, flights deviate from this ideal path, due to manoeuvring, traffic, airspace restrictions, and controller instructions. Aircraft cruise at a constant altitude, where in reality the cruise altitude may vary due to the influence of traffic or weather. In addition, climb and descent are simulated as continuous profiles. In a real flight, the pilot has to wait for controller approval to change to another altitude, which results in climb and descent being flown in altitude steps. Finally, for the simulation airspace restrictions are neglected. The simplifications mentioned above imply that the flight paths in the simulation differ from real flight paths. It is assumed the differences are minor enough not to have an impact on the validity of the simulation.

2.3.2 Conflict Resolution

FACET does not support conflict resolution in Flight plan mode. Conflicts will occur in the simulation even in the baseline scenario without reducing the aircraft cruise speed. It is assumed that the conflicts occurring in the baseline scenario would be

resolved without a change to the current controller workload. A change in the controlled workload is reflected by the increase of the number of conflicts compared to the baseline scenario.

2.3.3 Weather Impacts

In this research, no weather based airspace obstructions or wind influences are simulated. Weather has no effect on aircraft paths flown in the simulations and all flights can follow their "ideal" paths. The objective of this research is to investigate the effects of a change in aircraft cruise speed to the NAS. It is not possible to change the cruise speed of an aircraft in FACET. Only the groundspeed of aircraft can be altered using the FACET API. Groundspeed is the airspeed plus the wind vector. To change the cruise speed of an aircraft in FACET wind has to be neglected, so that cruise speed equals groundspeed.

2.4 Scenarios Evaluated

For this study, a number of different scenarios are evaluated to look at potential future situations of how a change in aircraft cruise speed may occur and impact the NAS.

2.4.1 Independent Variables

Three independent variables were changed to generate different scenarios in order to investigate potential future situations.

The population subgroup is a specific group of aircraft of the entire population that shares a common characteristic. Specifically, aircraft were aggregated by aircraft group, by aircraft type and by airline. This variable stands in relation to the stakeholders that can influence how aircraft are operated. As an example, an airline can decide which cruise speed their aircraft are flying taking into account for instance labor cost and fuel prices.

A second independent variable is the percentage of population subgroup. This

variable allows the emulation of the effect of a step-wise propagation of a change in aircraft cruise speed through the population subgroup. For example only 10% of a specific population subgroup could be affected by a reduction of cruise speed.

The third independent variable is the cruise speed. The cruise speed can be changed by a specific amount, by a specific percentage, or set uniformly to a fixed number.

2.4.2 Baseline Scenario

In order to investigate the impact of potential future scenarios, the results are compared to a baseline scenario which represents the current situation in the NAS.

In the baseline scenario, the speed of aircraft in the simulation was not changed and instead determined by FACET's aircraft performance data and calculations.

The results of a cruise speed reduction from all other scenarios are compared to the results of the baseline scenario and the relative change evaluated.

Since FACET does not resolve conflicts in Flightplan mode, conflicts occur in the baseline scenario. It is assumed that the number of conflicts occurring in the simulation of the baseline scenario naturally occur within the NAS. These conflicts are cleared by an air traffic controller and contribute to the current level of controller workload. A change in the number of conflicts will also change the number of controller interventions and therefore the controller workload.

The relative change in the number of conflicts resulting from a change in the cruise speed between the scenarios with an applied cruise speed reduction and the baseline scenario provides insight to how the NAS could behave under various scenarios of speed reduction.

2.4.3 General Speed Reduction

In this scenario, the population subgroup is not restricted. Any aircraft can be affected by the cruise speed reduction. The percentage of population subgroup is altered from 0% to 100% in steps of 10%. The aircraft cruise speed is reduced by 8%. For each

percentage of the population subgroup, aircraft are randomly selected from the entire population and affected by the cruise speed reduction.

This scenario simulates the effect of a step wise increase in the number of aircraft with reduced cruise speed. In this scenario, the selection of aircraft whose cruise speed is reduced is independent of stakeholders. This does not represent real life decision making, which is why it is unlikely to be put in practice. However it allows for the observation of system wide effects and the investigation of the effects of an increasing variation of speeds within the system. Also it can be seen as a worst case scenario, where random aircraft fly at reduced cruise speed, which results in the highest overall variation of speeds in the NAS. An increased variation in speed is expected to have a high influence on the number of conflicts.

2.4.4 Speed Reduction of Individual Airline

In this scenario, the population subgroup is a specific airline. To see system wide effect of the cruise speed reduction, the number of aircraft operated by the individual airline has to be large enough. Therefore the two major airlines Delta Airlines (DAL) and American Airlines (AAL) are selected as their fleet is a major fraction of the entire population. Again the percentage of population subgroup is altered from 0% to 100% in steps of 10% and the cruise speed reduced by 8%.

This scenario is likely to happen in reality, since an airline as a single stakeholder can decide to reduce fuel burn and emission and to gain an economic benefit if possible. The system wide impact of a single airline deciding to reduce cruise speed is expected to be small unless the airline's operations represent a major fraction of the total number of flights in the NAS.

2.4.5 Speed Reduction of Specific Aircraft Group

Aircraft in the Group III¹ category are the population subgroup for this scenario. Group III aircraft have a wingspan between 79ft and 118ft, and are comparable in

¹Based on the FAA Airplane Design Groups (ADG) specification [10]

size to the Boeing 737 and Airbus A320. They account for the majority of flights in the NAS. Thus reducing the cruise speed of Group III aircraft will lead to significant fuel burn benefits, but also have a system wide impact on the number of conflicts. The percentage of the population subgroup is altered from 0% to 100% in steps of 10%. The cruise speed reduced by 8%.

2.4.6 Speed Reduction of Specific Aircraft Type

For this scenario all 737-300 aircraft are chosen as the population subgroup. The percentage of the population subgroup is 100%. The average cruise speed of 737-300 aircraft is about 420kts. From this initial value the cruise speed is reduced in steps of 10kts to 100kts. In order to see a system wide effect the cruise speeds are chosen to be significantly different from the initial cruise speed. Some of the speed values chosen are below minimum take-off speed and therefore unrealistic, but were chosen to see a bigger effect on the system wide number of conflicts.

Chapter 3

Results and Analysis

In this chapter, the results of the simulations for the scenarios defined in chapter 2.4 are presented and discussed. As defined in chapter 2.4.1 the independent variables populations subgroup, percentage of population subgroup and speed are changed between the scenarios.

A day of traffic within the NAS was simulated in FACET to explore the effects of a cruise speeds reduction on the number and type of conflicts that occur in the NAS.

3.1 Baseline Scenario Without Change of Cruise Speed

The baseline scenario was run using flightplan data for August 24th, 2005. As described in chapter 2.4.2 the aircraft cruise speeds were determined by FACET. This scenario serves as a reference for the results obtained by the other scenarios.

In the baseline scenario 58,522 flights are operated in one day. Aircraft encounter a total of 12,827 conflicts which is an average of 0.217 conflicts per flight.

Figure 3-1 shows a distribution of the heading difference between the conflicting aircraft.

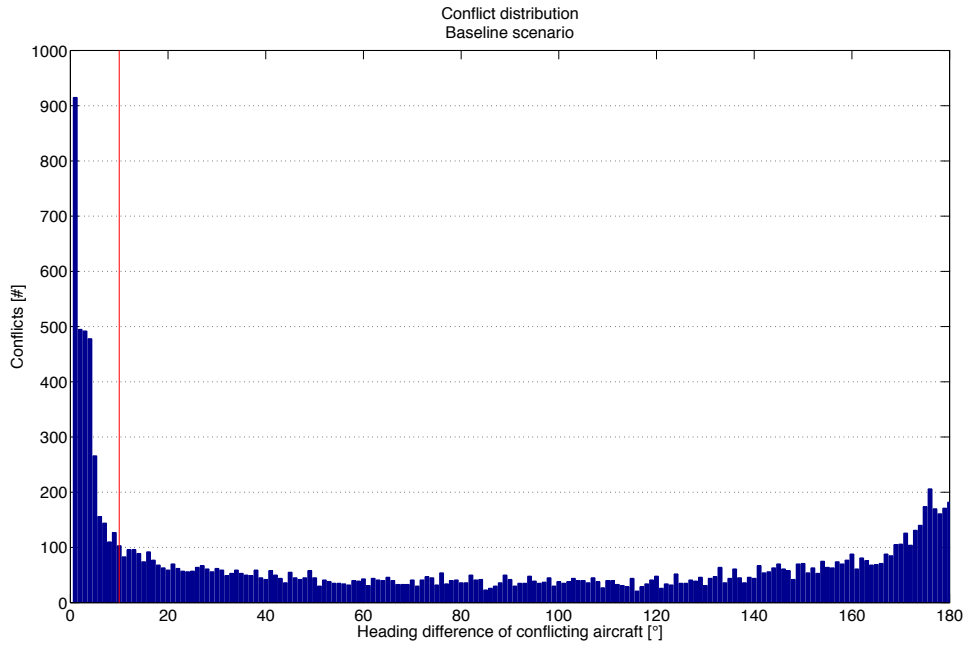


Figure 3-1: Distribution of heading differences between conflicting aircraft

As figure 3-1 illustrates a majority of conflicts in the baseline scenario occur as overtakes. In the baseline scenario aircraft encounter a total of 3,286 overtakes, which is an average of 0.056 overtakes per flight. This result motivates a more detailed analysis of the effect of the cruise speed reduction on the number of overtakes, where an overtake was defined as a conflict that occurs with a heading difference of less than 10° .

3.2 Results of Speed Reduction of 737-300 Fleet

As described in chapter 2.4.6 the cruise speed of the entire 737-300 fleet was incrementally reduced. The speeds were deliberately chosen to be significantly different from the baseline scenario to see a system wide effect.

In the baseline scenario, without any alteration of speeds, the mean groundspeed of the 737-300 fleet during cruise was recorded as 420kts.

Data about the conflicts occurring in US airspace was obtained from simulation and processed in MATLAB. Figure 3-2 illustrates the number of conflicts that occur

due to the speed reduction of the 737-300 fleet.

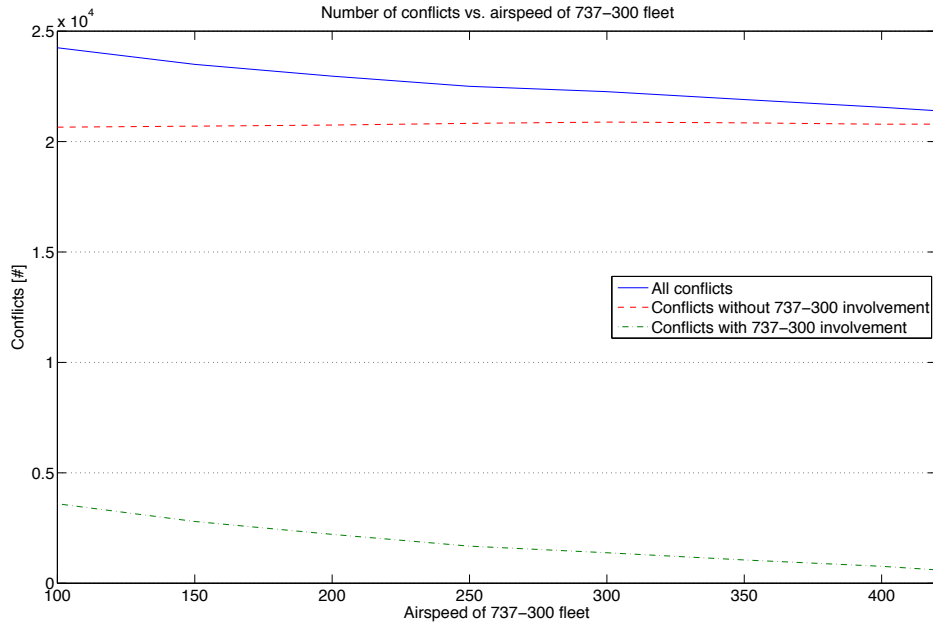


Figure 3-2: Number of conflicts vs. altered groundspeed of 737-300 fleet

As the speed of the 737-300 fleet decreases from 420kts to 100kts, the total number of conflicts increases from 21,390 to 24,250. The number of conflicts with an 737-300 aircraft involved increases from 604 to 3,598. The number of conflicts without 737-300 involvement stays approximately constant at 20,790.

Figure 3-3 shows the distribution of heading difference between conflicting aircraft of conflicts with 737-300 involvement above FL100, and thus shows under which conditions conflicts occur. The number of conflicts for the 737-300 fleet at 100kts increases compared to the baseline scenario for every heading difference. The majority of conflicts occur as overtakes under a heading difference between 0° and +18°.

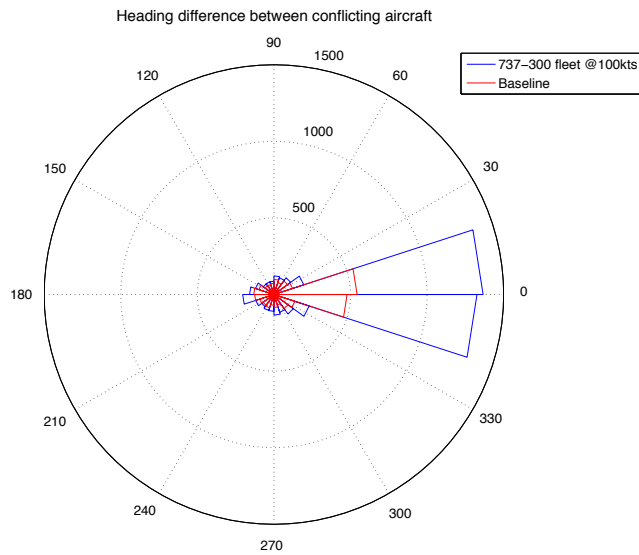


Figure 3-3: Rose plot of heading differences between conflicting aircraft. 737-300 fleet at 420kts and 100kts

Figure 3-4 shows the ratio of the number of conflicts of the 100kts scenario in terms of the 420kts scenario for each heading difference.

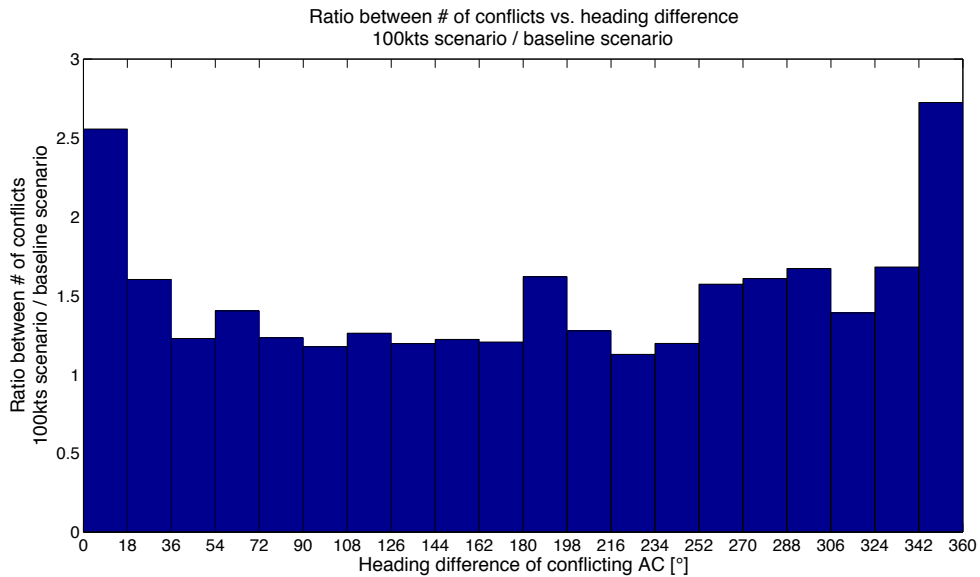


Figure 3-4: Ratio of the number of conflicts of the 100kts/420kts scenario vs. heading differences

It shows the change in the number of conflicts from the scenario without speed

alteration to the scenario where the ground-speed of the 737-300 fleet is reduced to 100kts. It is a representation of the ratio of the bins shown in figure 3-3. As it can be seen, the number of conflicts increases with a factor of at least 1.13 throughout all heading differences as the 737-300 fleet is slowed down from baseline speed to 100kts. The number of overtakes increases with a factor of up to 2.72.

3.2.1 Conclusion

This scenario was the first one to be simulated and used to develop and test the methodology of the analysis. Yet, the results show the influence of an aircraft cruise speed reduction to the NAS.

As the results indicate, the number of conflicts increases as a portion of the fleet is slowed down. The extent of this effect depends on the heading difference of the conflicting aircraft. Although it can be noticed for all heading differences, the increase in number of overtakes is the most significant as it increased by a factor of 2.72. From the results that were obtained, it stays unclear if the the increase in number of overtakes is linked to the actual speed change, or is a result of an increased variation of airspeeds in the NAS. This motivated an investigation of the effect of increasing the variation of speeds in the NAS in other scenarios where the speed reduction is kept constant and the fraction of percentage of fleet with reduced speed was changed.

3.3 Results of General Speed Reduction

As shown in section 3.2, a decrease of the cruise speed of the 737-300 fleet led to an increase in the number of conflicts, as well as an increase in the number of overtakes. However, the results did not indicate whether this increase was due to the actual speed flown or an increased variation of speeds. For this scenario, the magnitude of the speed change is constant, but applied to different percentages of the population subgroup to investigate the effects of an increased variation of speeds.

For this scenario, the cruise speed of a varying percentage of the entire population was reduced as described in chapter 2.4.3. The simulation was run five times for each

percentage of the fleet with reduced speed to average out variances in the results caused by the random selection of different aircraft. Figure 3-5 shows the average number of conflicts vs. the percentage of fleet that was slowed for all simulation runs.

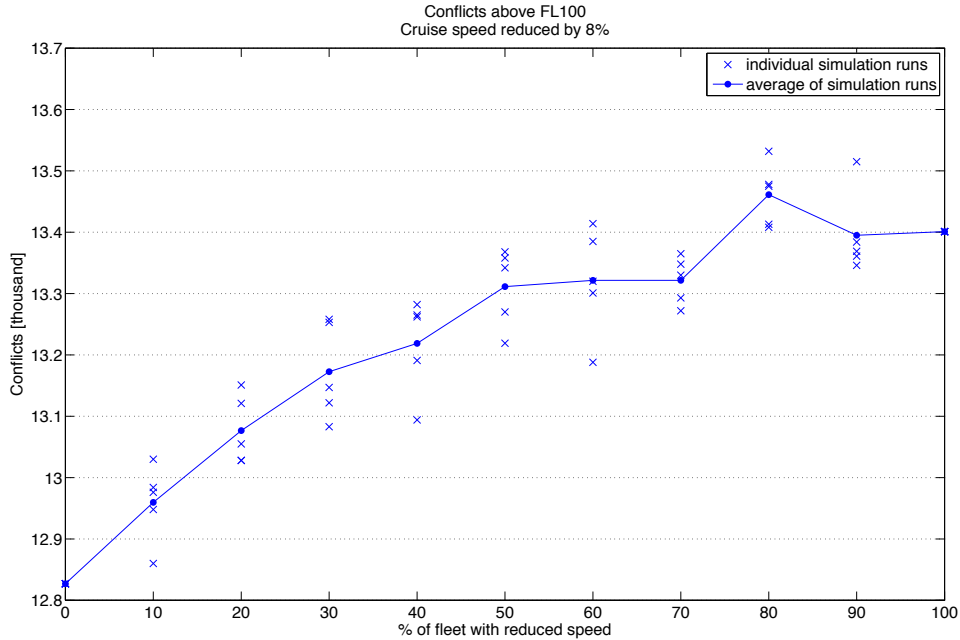


Figure 3-5: Number of conflicts vs. percentage of fleet with reduced speed

As a higher percentage of fleet is slowed down, the total number of conflicts increases. At the baseline where the speed of 0% of the fleet is reduced, the total number of conflicts is 12,827 (0.219 conflicts per flight). When 100% of fleet is slowed down, the number of conflicts increases to 13,401 (0.229 conflicts per flight). This corresponds to a 4.47% increase in the number of conflicts. The number of conflicts peaks at 80% of fleet with reduced speed where on average 13,461.2 conflicts were detected. This corresponds to a 4.94% increase (0.230 conflicts per flight).

Figure 3-6 shows the number of overtakes vs. the percentage of fleet with reduced speed. An overtake is defined as any conflict occurring at a heading difference between the two conflicting aircraft of 10° or less.

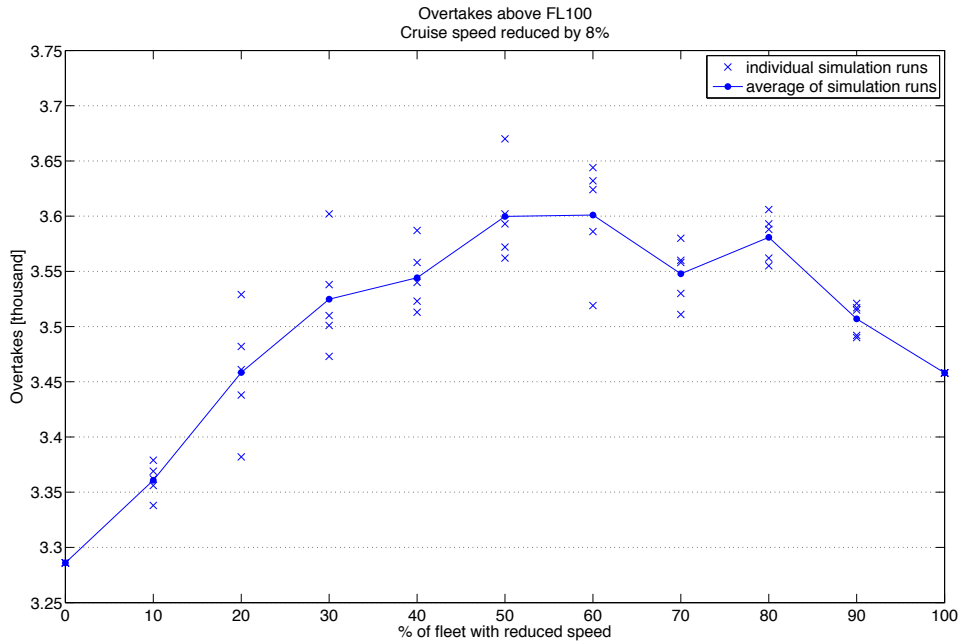


Figure 3-6: Number of overtakes vs. percentage of fleet with reduced speed

Between different simulation runs, the number of conflicts that are recorded varies, since a different set of aircraft is selected on each run. The number of overtakes seems to follow a normal distribution. The mean of all runs at 0% is 3,286 overtakes and increases to 3,458 overtakes when 100% of fleet fly a reduced speed. This corresponds to a 5.23% increase in number of overtakes due to the reduction of cruise speed (0.059 overtakes per flight). The number of overtakes peaks at 60% of fleet with reduced speed at 3,601 overtakes, which corresponds to a 9.59% increase or 0.062 overtakes per flight.

3.3.1 Further Analysis

At first glance the 4.47% increase in the number of conflicts that was presented in Figure 3-5 is unexplained. It is intuitively expected that by reducing the cruise speed of all aircraft, the total number of conflicts would be equal to the baseline scenario, since the movement of the aircraft are just slowed down and thus the separation between the aircraft and the resulting conflicts should not change. Upon further analysis it becomes evident that without changes to the schedule, the cruise speed

reduction leads to an increased number of aircraft flying in the airspace at any given time. The increase in the number of aircraft flying explains the increase in number of conflicts. In figure 3-7, the number of aircraft flying within a day in the simulation is shown for the baseline scenario, as well as for an 8% cruise speed reduction.

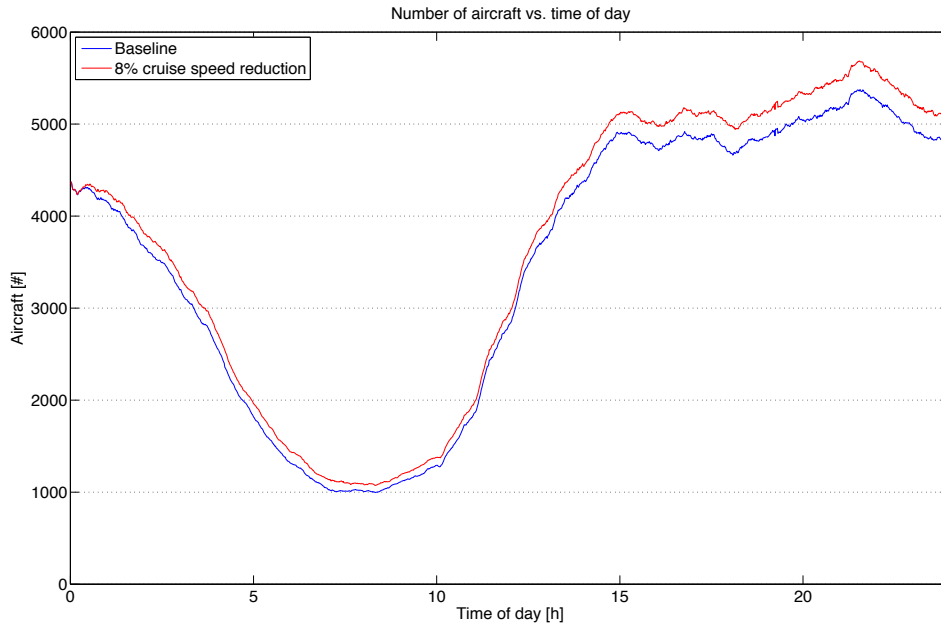


Figure 3-7: Number of aircraft vs. time of day

Comparing the scenario with an 8% cruise speed reduction to the baseline, the number of aircraft flying is higher throughout the day when aircraft are slowed. The average number of aircraft flying is 3,475 in the baseline scenario and 3,657 in the scenario with an 8% cruise speed reduction, which is equivalent to a 5.24% increase.

To assess this effect in more detail, simulations were also run for cruise speed reductions of 2%, 4%, 6% and 12%. Figure 3-8 shows the increase of the number of aircraft, as well as the resulting increase in the number of conflicts. The results show that the average number of aircraft flying increases linearly for each percentage reduction of cruise speed. As a result of the higher number of aircraft, there is a higher density of aircraft, and as a result the number of conflicts increases as well.

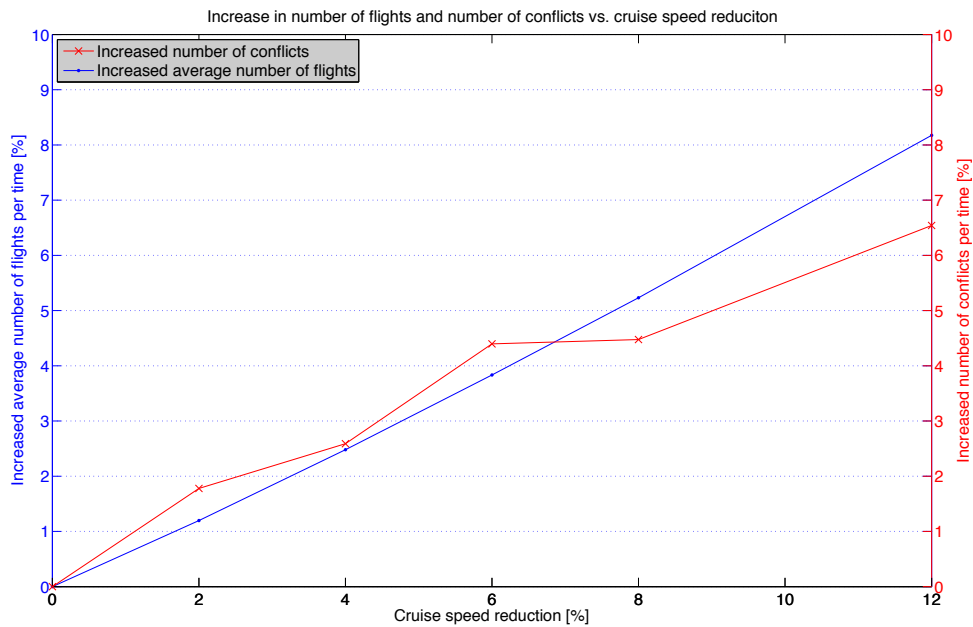


Figure 3-8: Increase of average Number of aircraft flying and increase of number of conflicts for different cruise speed reductions relative to baseline

3.3.2 Conclusion

The results show a correlation between the variation of speeds flown and total number of conflicts in the NAS. The airspeed of the fleet was reduced by 8%. With a reduced airspeed, the number of conflicts increases. This increase is under 5%. As they account for a major portion of the number of conflicts, overtakes were investigated as well. The number of overtakes seems to follow a normal distribution. In the baseline scenario 3,286 overtakes are detected. As the speed of a higher percentage of the total fleet is reduced, the number of overtakes increases to 3,601 at 60% of fleet with reduced speed where the variation of speeds in the NAS is at it's maximum. The maximum increase of the number of conflicts is 9.59% or 0.062 overtakes per flight. Figure 3-9 illustrates that in the case where the maximum number of overtakes occurs, there are two distinct areas, where most aircraft are flying.

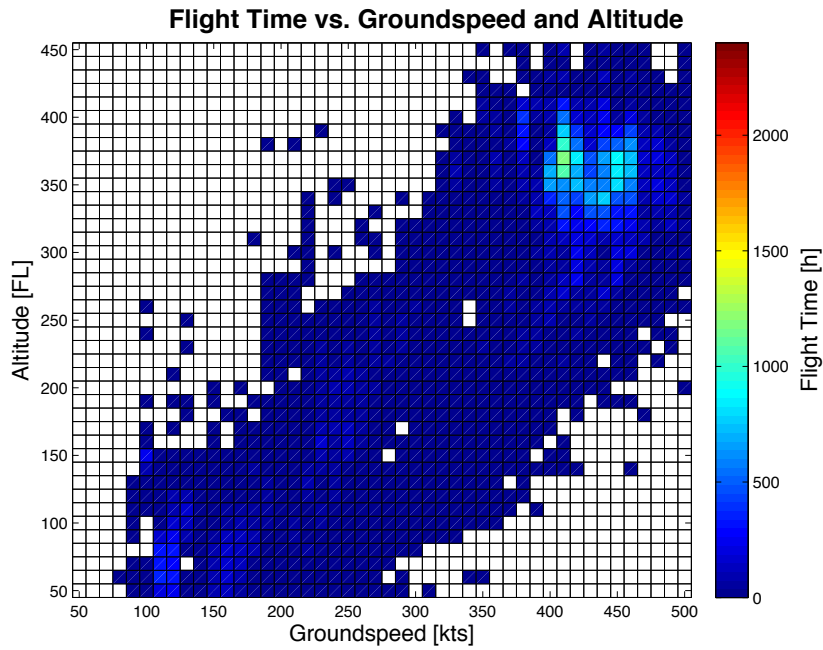


Figure 3-9: Number of overtakes vs. percentage of fleet with reduced speed

If the percentage of fleet is increased further, the number of overtakes decreases again, as aircraft fly more uniform airspeeds. A correlation exists between the variation of speeds and the number of conflicts.

As 100% of fleet fly at the reduced speed, the number of overtakes is 3,458, which is a 5.23% increase. The number should be equal to the number observed at 0% since the relative speeds between aircraft are the same. The increase can be explained with an increased number of aircraft flying as discussed in chapter 3.3.1.

3.4 Speed Reduction of Group III Aircraft

As described in chapter 2.4.5, the cruise speed of varying percentages of Group III aircraft is reduced by 8%. The simulation was run three times and different aircraft were randomly selected.

Figure 3-10 shows the number of conflicts that occurred in US airspace when different percentages of the fleet of Group III aircraft were flown at reduced speed.

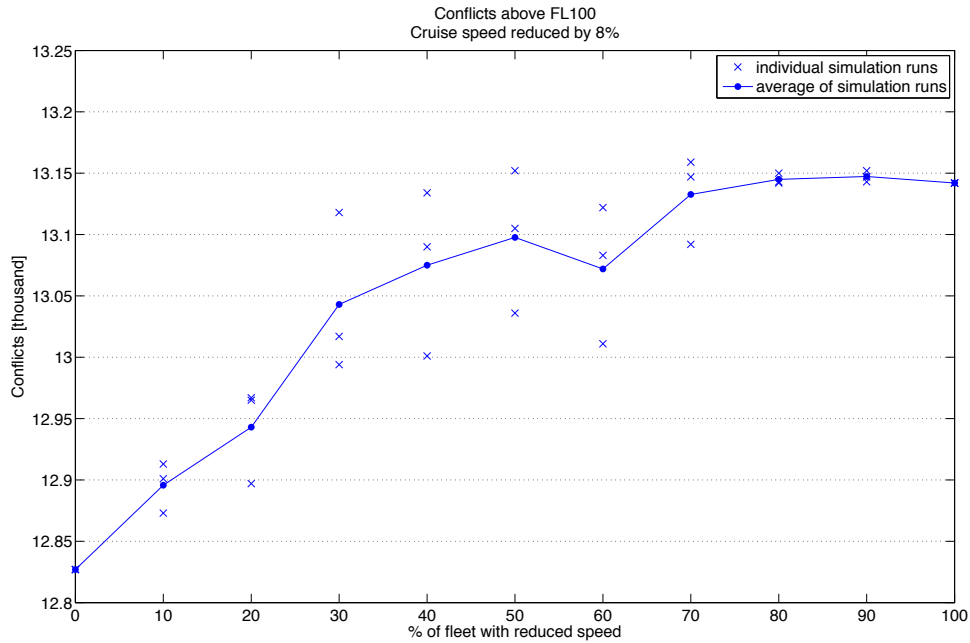


Figure 3-10: Conflicts occurring when a percentage of the Group III aircraft fleet has a reduced cruise speed

As the cruise speed of 0% of group III aircraft is reduced by 8% 12,827 conflicts occur in the system. When the cruise speed of 100% of Group III aircraft is reduced, 13,142 conflicts occur in the system. This is an increase of 2.46%. (0.225 conflicts per flight). At 90% of fleet with reduced speed the number of conflicts reaches its maximum at 13,157.3, which is a 2.50% (0.225 conflicts per flight).

Figure 3-11 shows the number of overtakes that occurred in US airspace for different percentages of the fleet of Group III aircraft at reduced speed. In the baseline case where the speed of 0% of Group III aircraft is altered, 3,286 overtakes are recorded. As the speed of more aircraft is reduced the number of overtakes increases. It peaks at 3,510.3 overtakes at 70% of Group III aircraft with reduced speed, which is an increase of 6.83% or 0.060 overtakes per flight. Reducing the speed of more aircraft leads to a decrease in number of overtakes. When all Group III aircraft cruise at an reduced speed, 3,484 overtakes occur, which correlates to an increase of 6.03% (0.056 overtakes per flight).

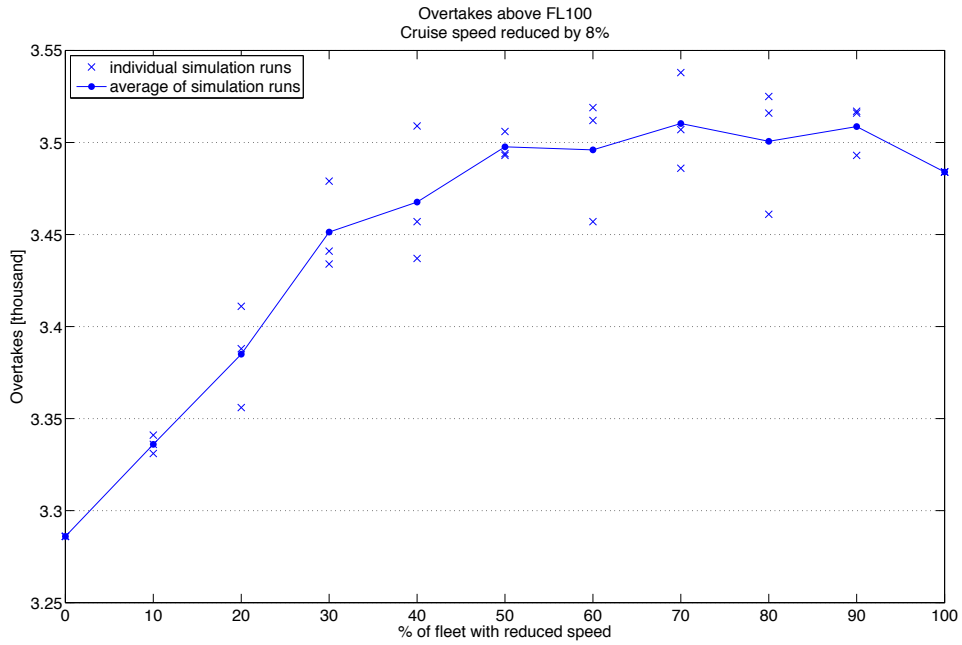


Figure 3-11: Overtakes occurring when percentage Group III aircraft fleet has reduced cruise speed

3.4.1 Conclusion

Reducing the cruise speed of Group III aircraft by 8% shows a system wide effect on the number of conflicts. As the speed of a greater percentage of aircraft is reduced, the number of conflicts increases. It peaks at 70%, where the system wide variation of speeds is at it's maximum. Decreasing the speed of more aircraft reduces the overall variation in speed and leads to a decrease in number of conflicts. At 100% of fleet with reduced speed aircraft on average encounter 0.225 conflicts.

3.4.2 Individual Airline

In this scenario, the cruise speed of Delta Airlines (DAL) and American Airlines (AAL) fleets is reduced by 8% as described in chapter 2.4.4.

Figure 3-12 shows the number of overtakes that occur when the cruise speed of the Delta Airlines fleet is altered.

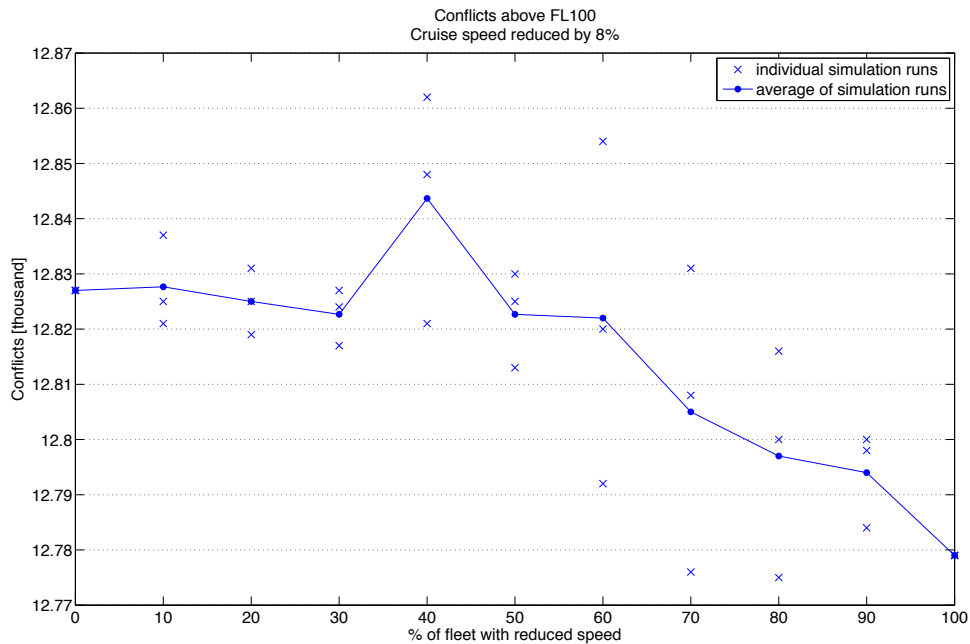


Figure 3-12: Conflicts occurring with cruise speed reduction of Delta Airlines fleet

In the baseline case 12,827 conflicts occur system wide within a day. As the percentage of Delta Airlines (DAL) fleet with reduced speed increases, the system wide number of conflicts decreases and reaches it's minimum at 12,779 conflicts, which is equivalent to a decrease of -0.37% (0.218 conflicts per flight).

Figure 3-13 shows the number of overtakes that occur when the cruise speed of the Delta Airlines fleet is altered. In the baseline case 3,286 overtakes occur within the system per day. As the percentage of fleet with reduced speed grows, the system wide number of overtakes increases to 3,297 overtakes, which is equivalent to an increase of 0.33% (0.056 overtakes per flight).

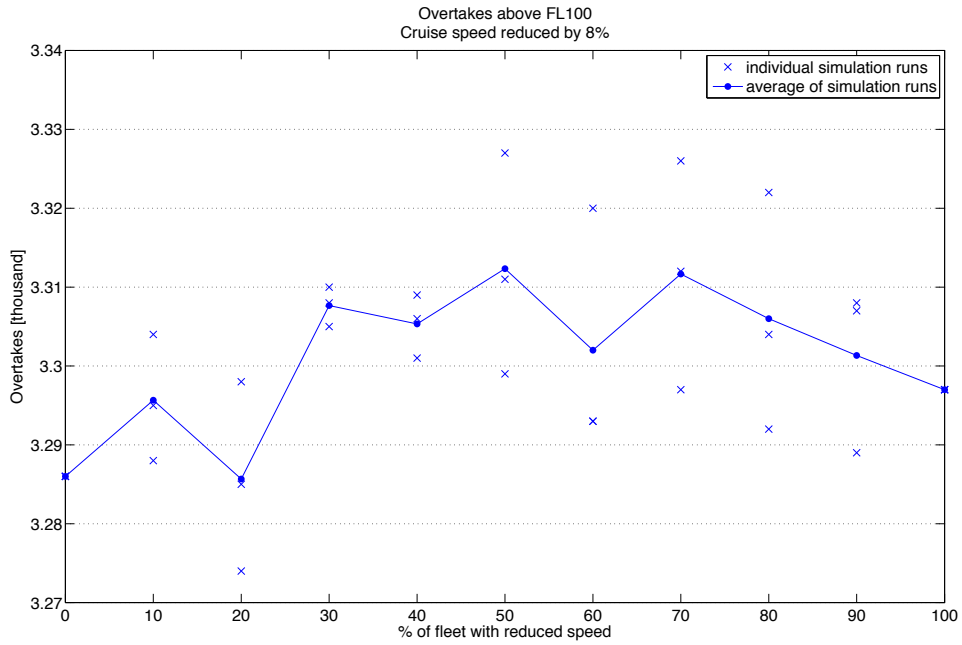


Figure 3-13: Overtakes occurring with cruise speed reduction of Delta Airlines fleet

The same scenario was run for American Airlines (AAL). Figure 3-14 shows the resulting system wide number of conflicts.

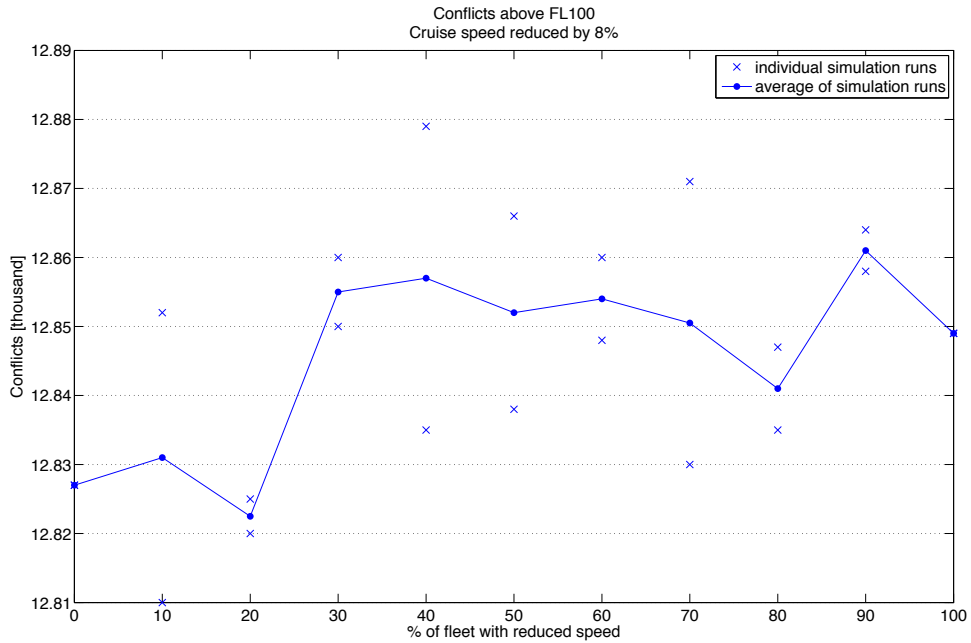


Figure 3-14: Conflicts occurring when the cruise speed of a percentage of the American Airlines fleet is reduced

From the baseline number of 12,827 system wide conflicts the number of conflicts increases and reaches it's maximum at 12,861 conflicts at 90% of fleet with reduced speed. If the cruise speed of the entire American Airlines fleet is reduced, 12,849 conflicts occur, which is a 0.17% increase (0.220 conflicts per flight).

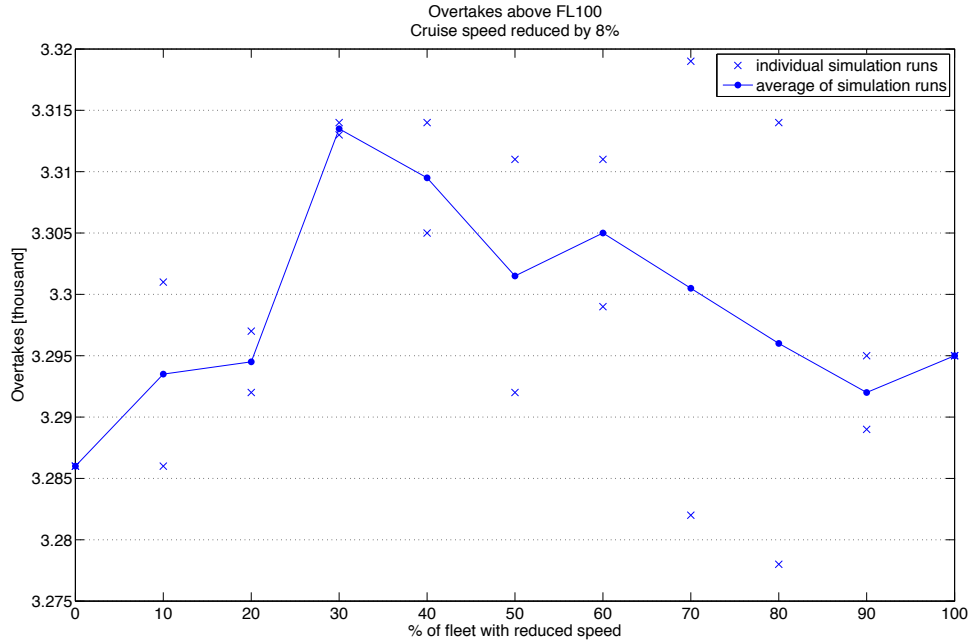


Figure 3-15: Overtakes occurring when percentage American Airlines fleet has reduced cruise speed

Figure 3-15 shows the resulting system wide number of overtakes. From the baseline number the system wide overtakes increase and reach its maximum at 3,313.5 overtakes at 30% of fleet with reduced speed. At 100% fleet with reduced speed the number of overtakes is 3,295, which is a 0.27% increase or 0.056 overtakes per flight.

3.4.3 Conclusion

At first glance, the result of this scenario contradicts what has been observed in the Aircraft Group and Entire fleet scenarios, since the number of conflicts decreases for the Delta Airlines case as more aircraft fly at a reduced cruise speed. In the American Airlines case the number of overtakes increases, but the increase is small compared to the other scenarios. A detailed analysis explains that the decrease for the Delta

Airlines case is due to the fact that a majority its fleet consists of modern aircraft which are modelled in FACET with a higher than average cruise speed. Reducing the cruisespeed of these aircraft leads to an overall decreased variation of speeds, which accounts for a decrease in number of conflicts. This result supports that the airspeed itself does not contribute to the number of conflicts rather the variation of speeds flown in the NAS accounts for the number of conflicts significantly.

3.4.4 Summary

In this chapter, different groups of aircraft were selected form the fleet and the cruised speed was reduced uniformly by 8%. The number of conflicts occurring in the US airspace was recorded and analyzed. The occurrence of conflicts and overtakes during cruise under different scenarios was presented.

All scenarios were compared to the same baseline case, where the speed was not altered. In comparison the "entire fleet" scenario shows the biggest increase in the number of conflicts, with a maximum of 13,461.2 conflicts at 80% of fleet with reduced speed. This is a 4.49% increase over the baseline scenario and corresponds to 0.230 conflicts per flight.

Chapter 4

Conclusion

4.1 Implications

In this study, the effects of a fuel burn motivated reduction of the aircraft cruise speed on the National Airspace Systems have been evaluated. Using the FACET simulation environment, a simulation of various scenarios of the traffic in the NAS has been performed. The number of overtakes occurring in the NAS has been chosen as a metric to investigate the effects of the cruise speed reduction. All simulation results were compared to a baseline scenario which is a simulation run with no changes to cruise speed.

The results of the simulations show that reducing cruise speed does influence the number of conflicts in the system. They indicate that the effect of the simulated 8% cruise speed reduction is relatively minor. The worst case shows an additional 634 conflicts that need to be cleared by a controller compared to the baseline scenario. This represents a 4.94% increase in the number of conflicts or 0.230 conflicts per flight. As discussed in chapter 1.1.2, according to Laudeman et al. [4] the number of conflicts occurring in the system does have an impact on the controller workload, which according to Ehrmanntraut and McMillan [7] is the capacity limit in today's air traffic control system. A large increase in the number of conflicts and a resulting increase in controller workload would not be feasible as it contradicts the NextGen goal to increase the ATC system capacity.

To emulate the effect of a step by step propagation of the speed change, the percentage of aircraft with reduced cruise speed is altered between 0% and 100%. This had not only an effect on the number of conflicts, but especially on the number of overtakes that occur in the system. The results show that the number of overtakes does not primarily depend on the speeds that are actually flown in the system, but more on the system wide variation in speed.

In the baseline case, 3,286 overtakes occur in the entire system. For the scenario where a general cruise speed reduction of 8% was simulated a maximum of 3,601 overtakes were recorded at 80% of fleet with reduced speed. This represents a 9.59% increase or 0.062 overtakes per flight. As the percentage of fleet with reduced cruise speed is increased further, aircraft fly at a more equal, but slower speed and the number of overtakes decreases to 3,458.

The study indicates that in transitioning the fleet to slower speeds an increase in conflicts of less than 6% and an increase of overtakes of less than 10% compared to the today's baseline scenario can be expected. Furthermore, the number of conflicts and overtakes will once again reduce as the majority of the system transitions and the system wide variation in speeds is reduced.

4.2 Future Work

The system wide impact of changes in cruise speed has been investigated using the number of overtakes as a metric to show an impact on controller workload. For future work, the effect on further metrics could be investigated. It seems most likely that the sector counts would be influenced, since aircraft at reduced cruise speeds are in the air for a longer period of time for a mission. Flying the same schedule, more aircraft would be in the air at any given time thus increasing the number of aircraft per sector. FACET offers tools to analyse sector and area metrics and compare them to the Monitor Alert Parameter (MAP), which is the maximum number of aircraft allowed in each sector, or other sector and area counts. It is yet to be determined whether FACET allows a higher than MAP number of aircraft in a sector, which

would allow a direct comparison between a baseline scenario and a scenario with a reduced cruise speed. If FACET caps the maximum number of aircraft per sector, it would have an effect on the arrival time of aircraft, which could be compared between a baseline scenario and a scenario with a reduced cruise speed.

This study does not discuss the real effect on controller workload. A more detailed study could cover the controller behaviour to clear overtakes and measure controller workload in such situations.

The results from this study show that the expected increase in number of conflicts is relatively minor. The main stakeholder that will benefit from fuel burn reductions, that result from a reduced cruise air speed, are the airlines. However the speed reductions impact other airline costs that result from a higher operational time such as payroll costs and a reduced maximum number of operations per day. The impacts on airline operation and the resulting airline behaviour can be investigated further. Additional incentives might be required to change the airline behaviour. One idea might be to give airplanes that are operated at fuel burn optimal cruise speed higher priority in the terminal area to make up the time lost during cruise. Penalizing CO₂ emission would be another way to create incentives for a reduction of cruise speeds.

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