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# Estimating ATM Efficiency Pools in the Descent Phase of Flight

## Potential Savings in both Time and Fuel

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**Abstract— In the descent phase of flight, limited research has focused on the benefits of ATM improvements in an environment where flight times are constrained by capacity. Both NextGen and SESAR have prioritized increasing capacity to reduce congestion and absorb future demand. For the foreseeable future, ATM will always have to manage congestion. This paper focuses on a methodology for estimating the total benefit pools, in terms of time and fuel that ATM can potentially influence in the descent phase of flight. Best practices from existing research on efficiency pools are incorporated and refined to provide estimates with data commonly available in today's ATC system. The analysis shows that at busy airports, most of the additional fuel used on top of an unconstrained trajectory is directly related to the need to sequence aircraft. How to absorb time in a time constrained environment in the most efficient manner is a key issue. This paper explores the benefits of reducing speed in cruise to absorb delays currently managed in the terminal area. The findings estimate the unimpeded benefit pool, actionable by ATC in the terminal area, averages 3 minutes for the top 34 airports in both US and Europe, or approximately 100 kg. of additional fuel per arrival. The potential benefit of reducing speed in cruise (i.e. with no change in capacity) is estimated to be around 30 percent of the unconstrained benefit pool in a conservative scenario. These findings provide incentive for further research complementing the numerous studies related to optimal descent profiles, which are mainly associated with non-congested periods. The estimated benefit pool associated with speed control in this paper applies directly to optimizing congested periods.**

***Keywords-component; ATM Benefit Pools, fuel savings, speed control, delay methodology***

## I. INTRODUCTION

Airline tradeoffs between fuel and time depend on the business objectives of individual flights [1]. In an environment where flight times are constrained by capacity, absorbing necessary delay in the most fuel-efficient manner becomes the primary business objective of airlines.

In today's air transport system, weather reduces airport capacity regularly [2]. In response, the ATM system is required to absorb some delay near the airport in order to use all arrival capacity by keeping constant pressure on the runways to minimize system delay. When delay absorption around an arrival airport is projected to be too high for safety or operational reasons, aircraft are held back at their departure airports based on a projected arrival time [3]. This is practiced in the US as a Ground Delay Program (GDP), managed by the FAA Command Center. This practice is similar in Europe where Air Traffic Flow Management (ATFM) slots are allocated by the Central Flow Management Unit (CFMU).

Because delays are infused into the system at departure, the delayed flight may increase its cruise speed, and hence overall fuel burn in cruise, trying to make up some of the time lost at the departure airport.

Without an agreed time of *arrival*, flights compete for runway capacity on a first come first served basis. While in some cases this speeding up may benefit the individual airline, the tactical competition for runway resources results in additional delay absorption around the arrival airport and the added terminal area congestion increases system level fuel burn. ATM metering tools currently in use in the US and Europe have not focused on the use of speed control during cruise.

While there are numerous studies published related to the benefits of optimal descent profiles, most reflect benefits in non-congested periods and focus only on vertical flight inefficiencies[4] [5] [6] [7]. Robinson and Kamgarpour [8] estimated the benefits of optimal descent profiles during congested periods to be considerably less than in an unconstrained environment. Robinson and others have addressed the value of speed control in the cruise phase for terminal congestion, but no specific research has been published. With this background, there are two main objectives of this paper:

1) Propose a method for the calculation of total benefit pools that ATM can potentially influence from a distance of 100 nm to the runway (approximate for the descent phase) that incorporate both horizontal and vertical components. Compare the resulting benefit pool to previous studies.

2) Use the determined benefit pool to estimate the potential fuel that could be saved in the descent phase of flight through ATM managed speed reductions during cruise.

Both NextGen and SESAR have 4-D trajectories as basic tenants, which would implicitly involve speed control [2] [9] [10]. ATM has incentives to reduce congestion around terminal areas beyond saving fuel including reducing the workload associated with merging and spacing, and, reducing the safety risk associated with aircraft considering fuel related diversions to alternate airports.

This paper does not attempt to lay out the operational procedure for ATM to implement speed control. Success clearly relies on a partnership between ATM and the airspace users. The objective of this analysis is merely to provide an initial benefits estimate for purposes of an increased focus on the potential fuel savings with speed control strategies.

From a systems standpoint, speed control may include speeding up aircraft early in the queue to maximize throughput and reduce system delay. Once a queue is established, the key constraint is managing time to the arrival fix. Once flight time is constrained, fuel burn becomes the next key objective for all stakeholders (in addition to safety).

The methodology follows the following principles:

1) support the analysis of a large number of flights, without detailed wind, aircraft weight data required;
2) use surveillance data for position information;
3) use Base of Aircraft Data (BADA) table for aircraft performance information [11], and
4) potential benefit can be expressed in terms of time and fuel.

While this research is focused on the last 100 nm of flight (descent), the unconstrained method can be expanded to include other phases of flight (departure (the first 40 nm) and en-route (between the first 40 nm and the last 100 nm).

## II. TOTAL UNCONSTRAINED ATM BENEFITS POOL (DESCENT PHASE OF FLIGHT)

### A. Data

The fundamental data sources for this paper are the FAA Enhanced Traffic Management System (ETMS) and its European counterpart, the Enhanced Tactical Flow Management System (ETFMS). Both systems include radar information at approximately 1 minute apart for every IFR flight in the US, and 1 to 4 minutes apart in Europe. The relevant flight track information includes ground speed, altitude, latitude, longitude, and time at a particular point for a given flight.

Using flight track information, an algorithm is developed to detect and extract level-flight segments in the descent phase for nearly 6.5 million flights (US arrivals into top 34 airports in 2009). A level-flight segment is defined as any consecutive points with an altitude difference of less than 200 feet.

For aircraft performance, BADA tables provided by Eurocontrol are used. BADA has nominal fuel burn and nominal speed for cruise at each flight level for specific aircraft types.

### B. Unconstrained Benefit Pool Methodology

The unconstrained benefit pool actionable by ATM in the descent phase of flights is represented by the difference between an unimpeded trajectory and the actual trajectory flown. The total benefit pool represents the amount of time and fuel that could be saved with unlimited capacity and optimal trajectories.

One of the difficulties in assessing the difference between actual and unimpeded time and fuel is that both are affected by factors such as wind, temperature, aircraft weight, engine type, and airframe performance. The proposed methodology is an alternative approach that uses available ATM data to identify both, the ATC constraints that impact the trajectory in the vertical and horizontal dimensions, as well as the impact of those constraints on the excess time and fuel burn. This two-phased approach allows for separate insights into benefits in the vertical and horizontal dimensions. The basic construct is as follows:

Let $Opt(x)$ be the optimum trajectory with the best vertical profile for a flight of distance $x$ and let $x_0$ be the unimpeded distance for the same flight.

Furthermore, let $Act(x)$ be the actual trajectory with actual vertical profile for a flight of distance $x$.

Then the total benefit pool expressed in kg of fuel saved is the difference.

$$Fuel(Act(x)) - Fuel(Opt(x_0)) \quad (1)$$

This expression can be expressed as the sum of two differences:

$$Fuel(Act(x)) - Fuel(Opt(x_0)) = [Fuel(Act(x)) - Fuel(Opt(x))] + [Fuel(Opt(x)) - Fuel(Opt(x_0))] \quad (2)$$

Fig. 1 summarizes the proposed methodology.

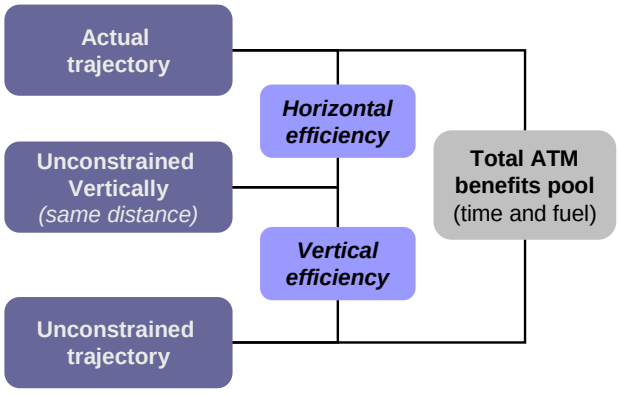


Figure 1. Combined horizontal and vertical process

The first part is the vertical component. It is the additional fuel to fly the same distance compared to an optimal vertical trajectory. The second part is the horizontal component. It is the additional fuel to fly the distance $(x\text{-}x_0)$ assuming both have an optimum vertical profile.

In the vertical phase, efficiency is calculated by comparing the fuel flown on the observed level segment to fuel burn under a scenario where the level segments that occur under climb or as part of descent are removed. This does not necessarily require calculating the fuel over the entire flight domain.

In the horizontal phase, efficiency is calculated by comparing the actual distance flown with ideal benchmark distance. The excess distance is then translated into excess fuel burn at cruise level.

Again, in the Unconstrained Case, neither flight path (distance) nor the flight profile (vertical) are constrained. Removing both "inefficiencies" result in reduced time and fuel. Details related to the specific calculations for horizontal and vertical inefficiency on descent are presented in the following steps:

Step 1: Remove Vertical Inefficiency

As stated earlier, the main driver for vertical inefficiency is assumed to be level flight segments flown at lower altitude. To increase efficiency and reduce fuel burn, level flight segments at lower altitude are assumed to be flown at cruise altitude. By moving level flight segment from lower altitude to a higher altitude, this method assumes the distance covered for each segment will be identical; however, speed and fuel burn will be different.

The BADA aircraft performance model gives fuel burn rates at each flight level for cruise, climb, and descent. By doing so, BADA assumes a nominal cruise speed and nominal cruise fuel burn at each flight level. From BADA tables, fuel burn at higher altitude is in general lower, but nominal cruise speed is higher. To cover the same distance at higher altitude, less time is needed and less fuel is used overall, as seen in Fig. 2 and 3.

In Fig. 2, the total distance flown is the same but the level segment is moved to a higher altitude.

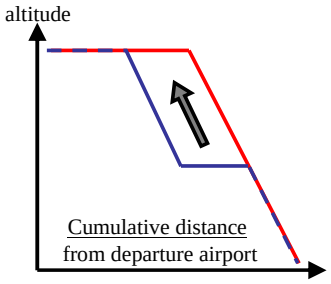


Figure 2. Shifting Level Segment to Cruise – Distance Perspective

In Fig. 3, by extending the cruise phase (higher speed) and removing the level segment, the overall time is shortened. As illustrated in the graphs, this method assumes flying distance will be kept the same before and after moving level flight segments. It also assumes that flying time is unconstrained and the flight can arrive before its actual arrival time.

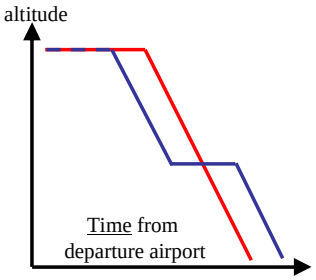


Figure 3. Shifting Level Segment to Cruise – Time Perspective

The relevant equations for this section are listed here:

$$\Delta T = \sum_{i=0}^{N} d_i \bullet (1/v(h_i) - 1/v(h_i^c)) \quad (3)$$

$$\Delta F = \sum_{i=0}^{N} d_i \bullet (f(h_i^c)/v(h_i^c) - f(h_i)/v(h_i)) \quad (4)$$

where,

$\Delta T$ is the change in duration as a result of moving level segments from lower altitude to cruise level,

$\Delta F$ is the change in fuel consumption as a result of moving level segments from lower altitude to cruise level,

$d_i$ is the length of level segment $i$,

$h_i$ is the original altitude of level segment $i$,

$h_i^c$ is the new altitude of level segment $i$ (cruise level),

$v(h)$ is the nominal cruise speed associated with altitude $h$ from BADA table,

$f(h)$ is the nominal fuel burn rate associated with altitude $h$ in cruise configuration from BADA table.

Step 2: Remove Horizontal Inefficiency

After step one the vertical trajectory is optimized, the excess distance associated with vectors or holding remains. As stated previously, the main driver for horizontal inefficiency is assumed to be excess distance, compared to a benchmark distance.

In the horizontal phase, a flight is broken up into three parts: the first 40 nm (departure), the last 100 nm (arrival) and everything in between (en-route). For each part, the actual distance flown and the great circle distance between the entry point and the exit for each phase can be calculated from flight track data. This methodology focuses on the arrival phase (last 100 nm). A benchmark distance, equal to the 20$^{th}$ percentile of actual distance flown for all similar flights (grouped by aircraft type, arrival fix, meteorological condition, runway configuration) into the same airport for the same quarter (season), is established for each flight. The determination for grouping by similar flights is taken from earlier calculation in the US Europe ATM Comparison Study [3]. The difference

between actual flown distance and benchmark distance is considered excess. This excess distance can then be converted to fuel burn based on values obtained from BADA tables at cruise altitude for each flight.

Fig. 4 illustrates an example of excess distance in the descend phase.

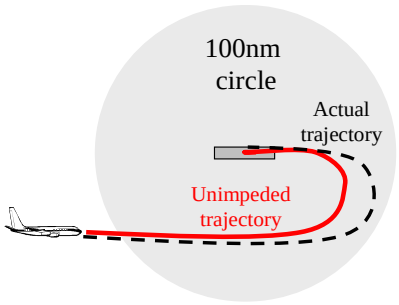


Figure 4. Illustration of excess distance in the descend phase

From the horizontal efficiency perspective, the black trajectory is the actual trajectory and the red trajectory is a nominal (unimpeded trajectory). In cases of holding or extended downwind legs the difference between the two horizontal trajectories may be much greater. The difference between the red trajectory and the black trajectory is the equivalent excess distance in the cruise phase. The overall distance and time is shortened with the unimpeded trajectory. This distance can be turned into saving in time and in fuel.

The relevant equations for this section are listed here:

$$\Delta D = D_{actual} - D_{benchmark} \quad (5)$$

$$\Delta T = \Delta D / \mathrm{v}(h_c) \quad (6)$$

$$\Delta F = \Delta D \bullet f(h_c) / v(h_c) \quad (7)$$

where,

$\Delta D$ is the change in distance as a result of removing horizontal excess distance,

$D_{actual}$ is the actual distance flown,

$D_{benchmark}$ is the benchmark distance for similar flights,

$\Delta T$ is the change in duration as a result of removing horizontal excess distance,

$\Delta F$ is the change in fuel consumption as a result of removing horizontal excess distance,

$h_c$ is the cruise altitude

$v(h_c)$ is the nominal speed associated with cruise altititude $h_c$ from BADA table,

$f(h_c)$ is the nominal fuel burn rate associated with cruise altitude $h_c$ from BADA table.

Step 3: Integration of Horizontal Phase and Vertical Phase

For the unconstrained scenario, the benefit pool is simply the sum of benefit pools from the horizontal and vertical phases.

## C. *Results for Unconstrained Benefits Pool*

The results show that, on average, the unconstrained benefit pool per flight from the vertical phase is 1.1 minutes and the fuel saved is approximately 29.6 kg; from the horizontal phase the benefit pool is estimated at 1.7 minutes per flight which corresponds to 50.9 kg. of fuel. In total, the unconstrained benefit pool per flight is 2.8 minutes and the fuel saved is 80.5 kg. The estimates are based on 6.3 million flights arriving into the top 34 US airports in 2009. The sample size represents 96% of all IFR flights arriving into OEP34 airports for the year 2009.

This study currently uses standard values from the BADA tables without adjustment. Robinson has pointed out in his paper that during the descent phase, some of the BADA values are underestimated [8]. He concluded, with adjustments to the BADA model, the median saving in terms of kg of fuel may be doubled. This adjustment would impact the vertical part only.

Fig. 5 and Fig. 6 depict the unconstrained benefits pool for both time and fuel. Each figure breaks out the vertical and horizontal contribution for each of the top 34 US airports.

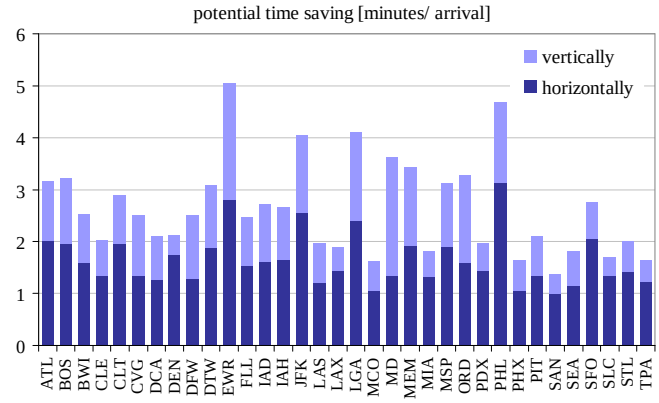


Figure 5. Potential time savings for unconstrained benefit pool at US airports in 2009 by dimension

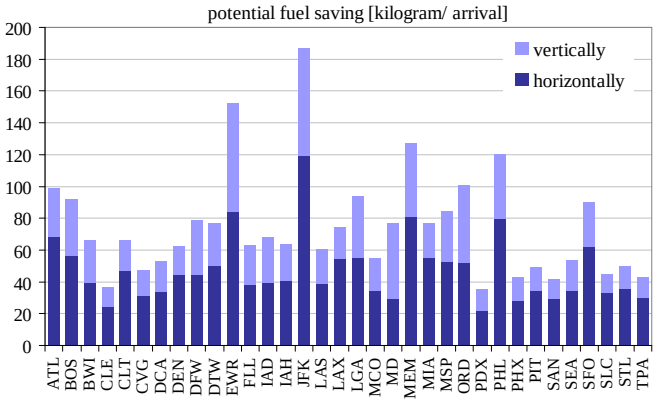


Figure 6. Potential fuel savings for unconstrained benefit pool at US airports in 2009 by dimension

Not surprisingly, the New York Airport group (JFK, LGA, EWR, and PHL) show the highest potential for improvement

### D. *Comparison to Time Based Method for Calculating Descent Inefficiencies*

Although the method proposed in the previous section is based on the identification of inefficiencies or "improvement opportunities" in the vertical and horizontal dimension, at congested airports, those inefficiencies are essentially caused by the requirement to sequence aircraft.

Fig. 7 is an example of the impact of congestion on flight times into London Heathrow airport. Excess time is a function of aircraft holding. At other congested airports, excess time during congested periods may be absorbed through extended vectoring and level segments.

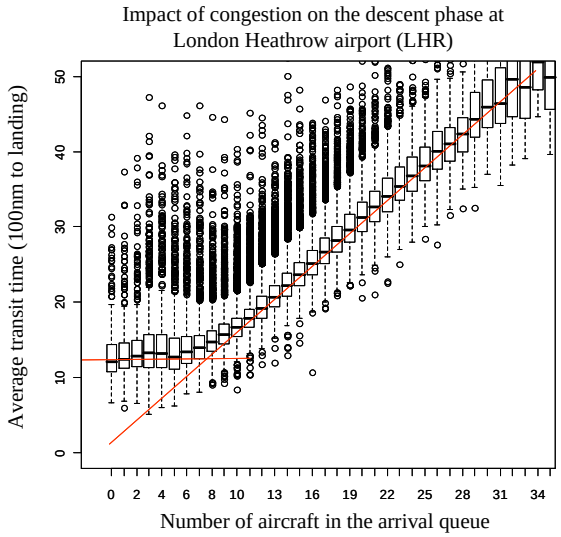


Figure 7. Congestion versus Flight Time

Presumably, with additional capacity, technology, and/or procedures, this congestion could be removed. In the nearer term, ATM actions can influence how this congestion delay is best absorbed to optimize fuel burn. In a constrained environment, fuel burn is the primary lever ATM can optimize. However, interdependencies with safety, weather and noise make the full fuel recovery of the proposed unconstrained pool unachievable.

In the 2009 US/Europe Comparison of ATM-Related Operational Performance paper [3], FAA and EUROCONTROL presented a methodology (A100 indicator) that calculates the additional time inside the last 100 nm circle of arrival airport for each flight into the top 34 airports in the US and Europe. This methodology establishes an actual and an unimpeded benchmark time inside the last 100 nm for each flight, based on a classification scheme that depends on the particular flight's arrival fix, runway configuration, and aircraft type. The unimpeded benchmarks are calculated using nominal speeds to cover the shortest distance from 100 nm to 40 nm for each classification of flights. From 40 nm to the airport actual landing times are grouped for similar classifications of flights. The unimpeded benchmark for this segment is based on the shortest flights (in total distance) present in the group. A final unimpeded benchmark is established from the two segments. The total benefits pool is based on the difference between the actual flights and the unimpeded benchmarks from 100 nm to the airport.

Both methods have advantages depending on data availability and the need for insight into vertical versus horizontal constraints. However, on an aggregate basis the results of the two approaches are fairly consistent across most airports as shown in Fig. 8. This figure shows a comparison of excess time between the A-100 time indicator versus the horizontal and vertical approach outlined in this paper.

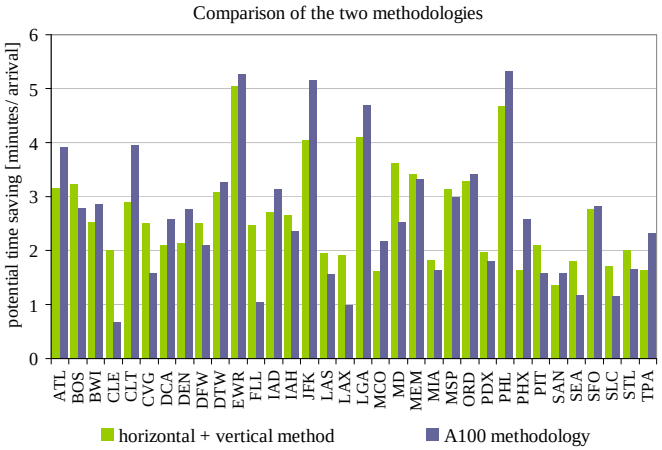


Figure 8. Comparison of time based inefficiency vs. combined distance and vertical efficiency

## III. Managing ATM Efficiency in a Time Constrained Environment

As discussed previously, direct recovery of the unconstrained benefit pools is primarily driven by adding capacity to reduce congestion. Assuming no change in demand, additional capacity (e.g. runways) will directly reduce delays. From an ATM perspective, the unconstrained benefit pool also quantifies the pool of delay that can be better managed through ATM. By improved absorption of necessary delay, fuel may be saved without reducing the maximum use of available capacity.

Robinson and Kamgarpour [8] propose a method for calculating a limited benefit pool during congested periods. The pool is strictly based on moving the time spent at lower altitudes to more fuel efficient higher altitudes. The overall flying time for each flight remains constant. Excess time absorbed in level segments is traded for the same excess time at higher altitudes which increases the actual distance flown. With nominal speeds from BADA, Robinson and Kamgarpour estimate that approximately 25% of the vertical benefit pool described above could be recovered. In a constrained environment, ATC must maintain peak throughput as well as manage delay. When delay must be managed, the goal is to absorb excess time in the most fuel efficient manner, *not to specifically manage excess distance or level segments.*

Achieving real improvement in terminal area trajectories during congested periods requires managing time prior to descent. Speed control during the cruise phase is the most fuel efficient ATM procedure for absorbing excess time [1] [8] [12].

While the methodology described in this paper focuses on the fuel savings from reduced cruise speeds, once congestion in the terminal is determined, increasing flight speeds at the beginning of a peak demand period can increase throughput and reduce overall delay and fuel. Use of speed control in the cruise phase for the purpose of absorbing terminal area congestion is limited in ATM. In both the US and Europe, most of the delay is absorbed around the airport to assure all available capacity is utilized. Ground delays at departure airports are implemented when projections of terminal congestion are adversely impacting controller workload, safety, and fuel efficiency [3]. In some cases, aircraft held on the ground will increase speed in cruise to make up lost time which then may result in a higher overall fuel burn, even though this was clearly not the system objective of the ATM imposed departure delay.

### *A. Background for Potential Benefits of Speed Control*

There are examples of ATM and airline strategic use of speed control during the cruise phase of flight:

1) Operational trials by United Airlines in conjunction with NATS estimated that reducing speed into Heathrow can save approximately 45 kg. of fuel per flight during the cruise phase. This does not include any savings associated with the reduction of the time due to 6+ minutes of delay absorbed en-route [13].

2) Airservices Australia had a problem with excessive holding during the morning rush into Sydney airport. For noise constraints, the airport does not open until 6am. Long haul flights were regularly arriving early, partially due to inaccurate wind forecasts and partially because those aircraft at the end of the rush were subject to even greater holding. Airservices Australia developed the ATM Long Range Optimal Flow Tool (ALOFT), which allows pilots to control speeds up to 1000 miles from Sydney airport during the morning peak. Airservices estimated annual fuel savings to be nearly 1 million kg in 2008 [14] [15].

3) Delta Airlines is using a dispatcher based system to slightly alter speeds in order to reorder their flights into Atlanta for business reasons [16]. This process begins when flights begin cruise level and is transparent to controllers. In the majority of cases where speeds are adjusted, they are increased for repositioning and to increase throughput early in the queue in an effort to reduce overall delay in an arrival bank[1].

All three of the above examples rely on the capability of aircraft flight management systems (FMS) to efficiently absorb needed time. In current practice across both the US and Europe, there is limited use of speed control en-route where the FMS capabilities are used. To maximize fuel saving benefits from reduced speeds in cruise for terminal congestion, a procedure is needed where all airlines participate equitably. If left to individual optimization, there can be an incentive for pilots to "rush-to-wait".

To achieve the full benefits of speed control, FMS capabilities would be part of the solution to absorb necessary time estimated by ground automation. However, a full description of an equitable procedure for creating a "virtual queue" for arrivals is beyond the scope of this paper.

As previously stated, the unimpeded benefit pool is the starting point on a flight by flight basis for calculating the time available for absorption during cruise. Each minute absorbed with speed control during cruise offsets inefficient delay absorbed in the terminal area. Additionally reduced speeds during cruise can further reduce fuel burn. Reducing cruise speed will reduce fuel burn when the actual speeds flown are higher than the maximum-range speed. In modern jet aircraft, the change in "miles per gallon" related to speed changes at cruise altitudes is minimal. Fig. 9 depicts the efficiency curve for an example aircraft [17].

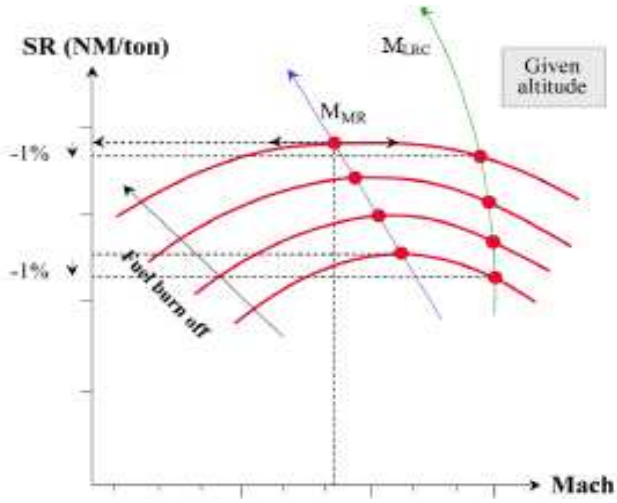


Figure 9. Comparison of time based inefficiency vs. combined distance and vertical efficiency

Since the actual cruise true-air-speed for each flight is not known, it is assumed for simplicity that, on average, time can be absorbed by slowing down *without* additional fuel burn. In reality, the change in fuel burn to cover the distance to the terminal area will vary from flight to flight while reducing speed could actually increase the fuel burned during cruise for flights already operating close to its optimum speed, average experience documented in the United Airlines trials into Heathrow, yielded fuel savings from slowing down in cruise [13]. For this reason, the benefit pool associated reducing terminal area delay through speed reduction during cruise may be understated.

To further investigate savings from reduced speed in cruise, additional data is needed for true airspeed and aircraft weight. Information from airlines on their normal operating practices along with BADA modeling could also be used to approximate these additional fuel savings. The United Airlines trials estimate this savings to be nearly equivalent to the offset of terminal delay captured here.

[1] Because Delta is operating with other airlines into Atlanta, unilateral speed reduction can result in moving further back in the arrival queue.

### B. *Methodology for calculating fuel savings from speed control in cruise*

Unconstrained benefit pool (both in terms of fuel saving and time saving) on a per flight basis is used as a starting point for this exercise.

As a conservative baseline for all carriers, it is assumed that speed can be reduced by up to 5% from the flight cruise speed. This is equivalent to saying that approximately 3 minutes can be added per flight hour.

Furthermore it is assumed that speed control is achieved in the last 90 minutes of the cruise, giving a maximum additional time en-route of 4.5 minutes.

As a high scenario, parameters can be changed to a speed reduction of 8% and a speed control duration of two hours. This is equivalent to a maximum of 10 minutes which can be added per flight during cruise.

Given the need to maintain pressure on the airport combined with current navigational accuracy to achieve desired arrival times, a threshold of 1.5 minutes of terminal area delay was considered.

From earlier results in part 1, if flight-specific additional time within 100 nm is less than or equal to 1.5 minutes, no change is made.

However, if additional time within 100 nm is greater than 1.5 minutes, aircraft speed reduction is used during the last 90 minutes of the cruise. For short haul flight time, cruise was assumed to start 15 minutes after take-off, therefore limiting the time that may be available for speed control.

With a conservative assumption of 5% speed reduction, it is found that up to 20% to 30% of the total unconstrained pool can be considered recoverable. Fig. 10 and 11 include airport level results for potential excess terminal area time absorbed in cruise as well as associated terminal area fuel savings for 34 US airports in 2009.

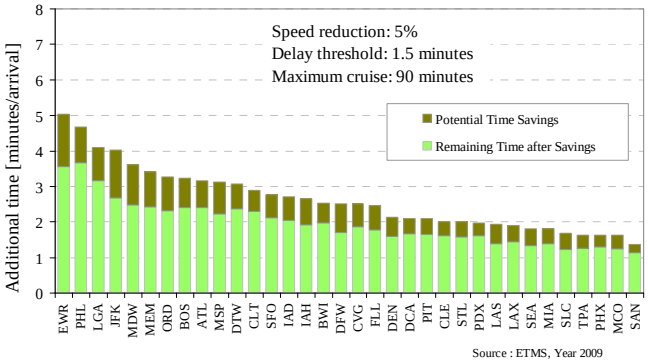


Figure 10. Potential time savings (US airports 2009)

As expected, the NY area airports (PHL, LGA, JFK, and EWR), have the potential for the largest gains. However, the difficulty in implementing speed control might also be highest in this area.

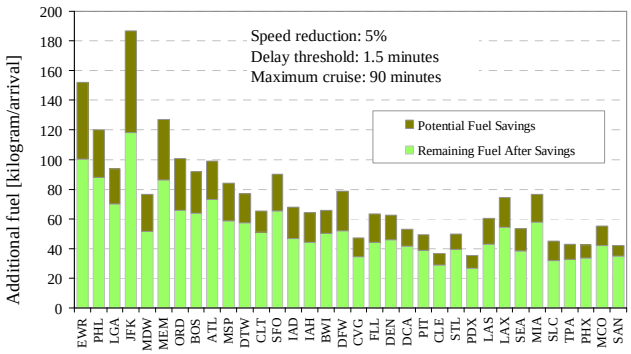


Figure 11. Potential fuel savings (US airports 2009)

Fig. 12 and 13 display potential time and fuel savings in the terminal area due to speed reduction in cruise for several constraining parameters. Both show actual curves versus look-ahead time from 40 to 100 minutes with the pairs of curves for different levels of navigational accuracy (1.5 minute and 2.5 minutes of remaining excess terminal time).

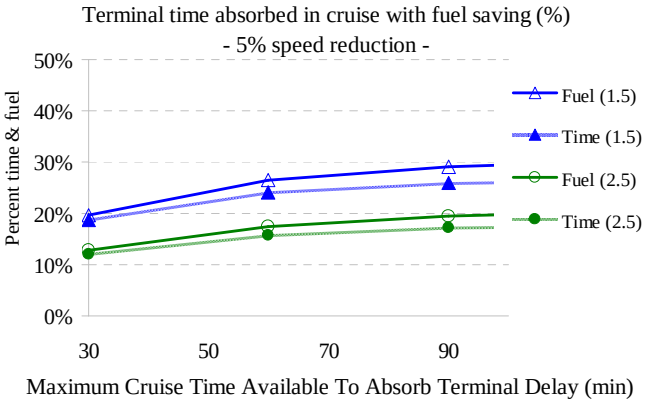


Figure 12. US - 5% max speed reduction

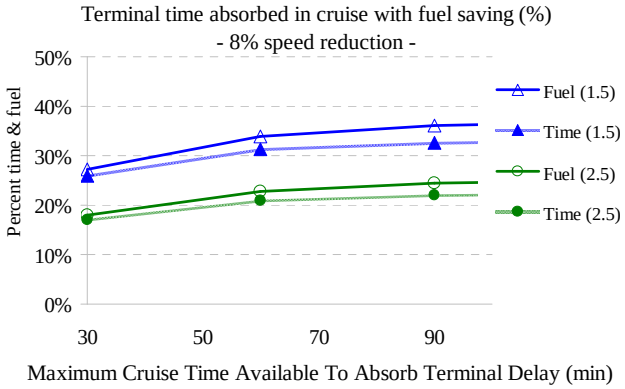


Figure 13. US - 8% max speed reduction

Fig. 12 provides the results with a maximum of 5% speed reduction while Fig. 13 shows the results for of up to 8% speed reduction. Note that in each case, the potential fuel savings percentage is larger than the potential time savings. This is due to the higher fuel burn rate for the longer flights (i.e., larger aircraft). With longer flights, there is more opportunity to

utilize the full time allowed for speed control. This also explains why at the shorter cruise time (40 min.) the curves tend to converge.

Fig. 14 and 15 show an estimate of the potential time and fuel savings in terminal areas through the application of speed control in cruise at the main European airports in 2009.

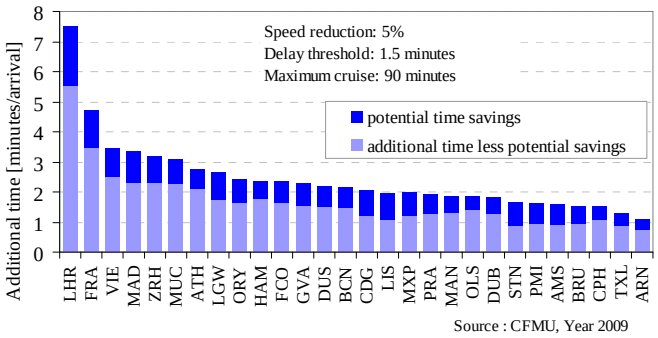


Figure 14. Potential time savings (Europe 2009)

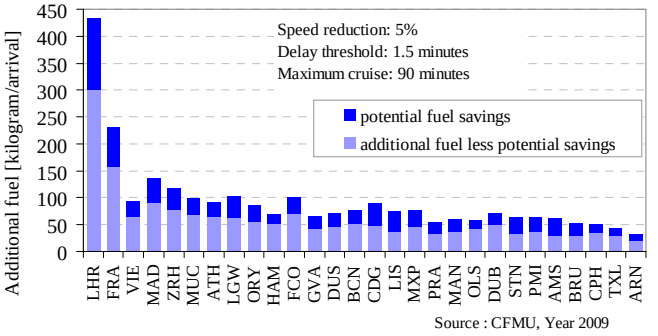


Figure 15. Potential fuel savings (Europe 2009)

London Heathrow (LHR) shows by far the highest potential in terms of potential time and fuel savings in Europe, followed by Frankfurt airport (FRA).

Fig. 16 and 17 depict curves for potential time and fuel savings in the terminal area as a function of available cruise times for speed reduction (same as US figures). The time and fuel curves are calculated for a threshold of 1.5 and 2.5 minutes of delay remaining in the terminal area.

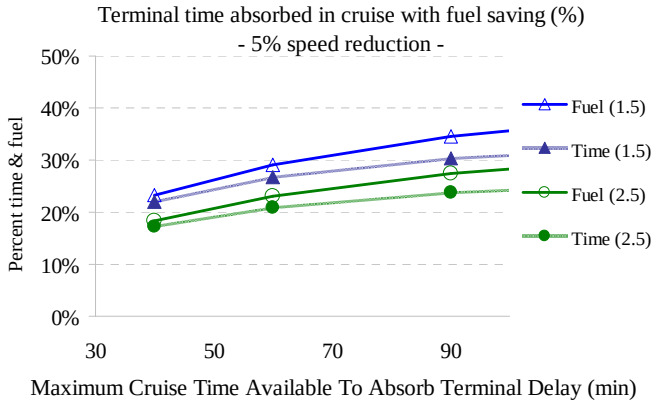


Figure 16. Europe 2009 - 5% speed reduction

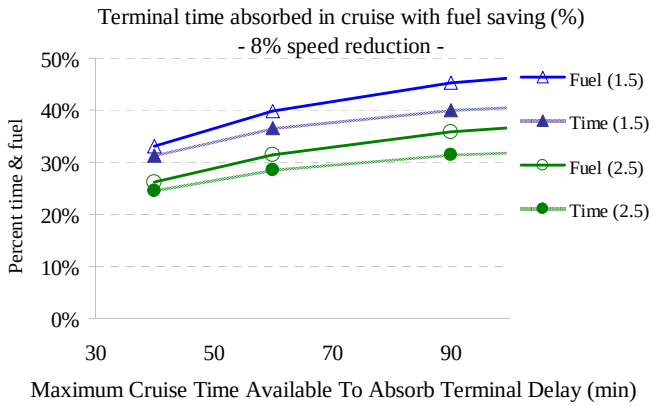


Figure 17. Europe 2009 - 8% speed reduction

Potential savings are directly related to the percentage of long haul flights arriving at an airport. Fig. 18 shows the relationship between the potential fuel savings from speed reductions in cruise versus the flight distance for Europe.

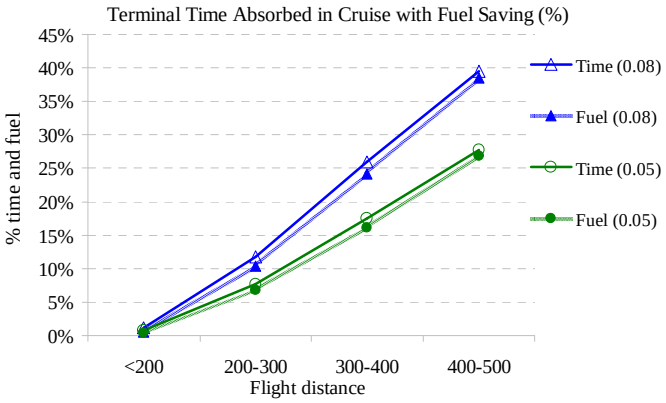


Figure 18. Fuel savings from speed control versus flight length (Europe 2009)

The comparison of the results for the US and for Europe suggests the potential fuel savings to be higher in Europe, often reaching between 30% and 50% of the unconstrained benefit pool. Some limitations in the US dataset may drive an increased vertical inefficiency bias, but overall results may still be conservative.

These results illustrate that international airports with long haul flights have the greatest potential for fuel savings. The potential savings may even be larger than estimated in this analysis, because the calculations are based on average fuel burn. Long haul aircraft are on average much larger and burn much more fuel per minute.

## IV. PRELIMINARY CONCLUSIONS

Considerable focus is being placed on the role of optimal descent profiles as a means to reduce fuel burn. Vertical and horizontal inefficiencies on descent are primarily a function of absorbing necessary time to manage runway capacity constraints. The results of this analysis show that in constrained periods, ATM management could start well before top of descent to reduce fuel burn. Conservative estimates indicate that more than 30% of the excess fuel burn on descent could be

reduced independent of increasing capacity through better combined ATM and airline procedures.

As illustrated in the analyses, long haul flights have the highest potential to save fuel through the application of speed control in the cruise phase of flight. Furthermore, the United Airline trials suggest that the recoverable pool in highly congested airports like London Heathrow is even higher [13].

Additional findings suggest that assessing benefit pools on descent using the combined vertical and horizontal inefficiencies produce similar results to the time based method introduced in the US Europe ATM Performance Comparisons. This total benefit pool is a key component of understanding the recoverable benefit pool related to improved ATM procedures, as well as additional arrival capacity.

More research is needed to further assess the potential larger benefits of speed control not captured in the basic methodology used in this paper. Additional research is also required to evaluate practical implementations of speed control.

The results in this paper aim at fostering more system level thinking when addressing ATMs role in managing delay along the trajectory in a time constraint environment. International collaboration on best practices will accelerate success. Organizations like the Civil Air Navigation Service Organization (CANSO) have a strong focus on best practices for fuel efficiency and $CO_2$ reductions. FAA and European ANSPs will need to continue collaboration with International organizations to establish procedures that can be applied consistently for airlines operating around the world.

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