EVALUATION OF POTENTIAL NEAR-TERM OPERATIONAL CHANGES TO MITIGATE ENVIRONMENTAL IMPACTS OF AVIATION

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Abstract

Changing aircraft operational procedures is one strategy that could be used to mitigate environmental impacts of aviation in relatively short timeframes with existing aircraft types. This study undertakes a comprehensive identification and systematic evaluation of potential near-term operational changes to determine their relative environmental mitigation benefits, as well as other factors such as barriers to implementation. This is used to identify promising mitigations for further study and possible near-term implementation.

1. Introduction

It is becoming increasingly necessary to understand and mitigate the environmental impacts of aviation [1,2]. Various strategies are being pursued, including developing advanced aircraft technologies and sustainable alternative jet fuels; creating new policies and standards; and modifying operational procedures. New technologies, sustainable jet fuels and policies can reduce environmental impacts significantly but require mid to long timeframes. Operational changes have smaller overall mitigation potential but can be implemented in much shorter timeframes with existing aircraft types and so are complementary to the longer-term approaches. Many operational mitigations specific to given flight phases have been suggested and investigated at various depths. For example, Continuous Descent Approaches (now evolving into Optimized Profile Descents) have been investigated extensively through field trials and are now fully operational at some airports, showing notable environmental impact reduction (e.g. [3,4]). In contrast, work on advanced surface movement optimization is still largely in the research stage (e.g. [5]), while other possible changes have yet to be fully defined, let alone studied in any significant depth. There is also growing interest from the air navigation service providers to understand the role that operational strategies available in each flight phase have on total mission fuel burn (and hence emissions), as illustrated by the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) and Asia and South Pacific Initiative to Reduce Emissions (ASPIRE) programs [6,7]. The Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) and EUROCONTROL Single European Sky ATM Research (SESAR) have also identified some near-term operational strategies that will be needed to achieve necessary system evolution, such as the NextGen Operational Improvements (OIs) [8]. The present study complements these activities by identifying and systematically evaluating a comprehensive set of potential near-term operational mitigations across all flight phases against a common set of environmental impact and feasibility criteria. This makes it possible to determine the relative potential of the various mitigation options.

For the purposes of this study, near-term is defined as having potential to be implemented within the next 5-10 years (i.e. slightly longer than the NextGen "near-term" timeframe which extends through 2012).

2. Methodology

The approach followed in this research is presented in Figure 1.

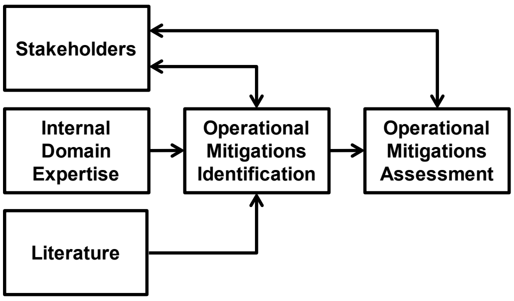

Figure 1. Research Approach

2.1 Operational Mitigations Identification

The first objective of the research was to identify a comprehensive list of near-term operational mitigations to include in the study. This was accomplished via a combination of detailed literature review (from academia, industry and government), domain knowledge internal to the research team, and an extensive stakeholder interview process. Interview subjects were identified by the researchers and FAA program managers based on their knowledge of the civil aviation industry. Stakeholders in a wide range of roles, including the regulators/policymakers, air traffic control (ATC), airlines, airports and research organizations were identified and interviewed in order to ensure diversity of views: see Table 1.

Table 1. Stakeholders Interviewed

Stakeholder	Organization	Department
Regulator	FAA	AEE: Project Managers x4
		ATO: Chief Scientist, Terminal Services, Environment Programs
		APP: Airport Planning
		ARC: NY Area Integration
		US/Europe Liaison
ATC	FAA/NATCA	Oakland En Route, DFW Terminal, LAX Tower
	ISAVIA	Iceland Oceanic
Airlines	Air Canada	Pilot
	Alaska	Airspace/Technol. Director
	American	Pilot
	United	Pilot
Airports	Massport	Environment Manager
	Port Authority of NY & NJ	Airspace Senior Advisor, Environment Manager
Research	NASA	NextGen Super-Density Ops
	CSSI	Environment Programs

A formal interview protocol was established to ensure consistency across the stakeholders. Possible near-term mitigation options, barriers and other key comments were distilled from the interviews, literature review and domain expertise to form a comprehensive list. The final version of this list contained over 75 mitigations which were then classified according to the phase of flight to which they applied: Surface (S); Departure (D); Cruise (C); Approach (A); Landing (L); and Miscellaneous (M). The identified mitigations were primarily operational in nature, but also included factors such as airline strategy (e.g. non-revenue flying, load factors) and non-operational policy (e.g. land use planning). These additional factors were raised by stakeholders but will not be discussed further in this paper in order to focus on the pure operational mitigations (61 in total).

2.2 Operational Mitigations Assessment

A qualitative assessment of the operational mitigations was then conducted against a common set of criteria, namely:

- Environmental impact
- Ease of implementation
- System-wide impact

For environmental impact, each mitigation was assessed against fuel burn (decrease or increase); climate (generally directly related to fuel burn, but not always, e.g. contrails); air quality (primarily related to fuel burn at low altitudes in the Landing and Take-Off (LTO) cycle); and noise (from changes to the noise being generated by the aircraft and/or the number of people being over-flown). Against each of these impacts, mitigations were rated as Primary (P), Secondary (S), Neutral (0), or Adverse (A). A mitigation was ranked as *Primary* if its main goal was to reduce the environmental impact in that category. It was rated *Secondary* if the primary goal was impact reduction in another category or a different type of operational improvement altogether (e.g., increasing capacity or managing congestion), but yielded environmental co-benefits in that category. A mitigation was ranked *Neutral* if it had no impact in that category, and *Adverse* if it increased the environmental impact in that category. Note that the primary motivation for a given mitigation need not be environmental, but instead could be for other reasons (such as congestion management). Therefore the qualitative assessment for such mitigations may not have any *Primary* evaluations against environmental metrics.

Ease of implementation in the near-term timeframe was rated as Easy, Medium or Hard. Mitigations were considered *Easy* if they had already been successfully implemented somewhere and did not require significant technology/infrastructure change or lengthy review. Mitigations requiring relatively uncomplicated technology or infrastructure additions (e.g. adding more (but existing) technology or building a new taxiway) or straightforward policy review were ranked as *Medium*. Mitigations were considered *Hard* if there were significant technical barriers, required major infrastructure addition or air traffic control changes (such as extensive airspace redesign), had stakeholder opposition or needed lengthy policy review.

Note that all Federal actions will require environmental review under the National Environmental Policy Act (NEPA) process [9] and the level of documentation needed to comply may have an effect on the ease of implementation of a mitigation. The initial review will determine the level of documentation required to comply with NEPA: categorical exclusion; Environmental Assessment (EA); and, Environmental Impact Statement (EIS). If an action is listed as a categorical exclusion and there are no extraordinary circumstances, then the action can proceed without further environmental review. Actions that do not qualify for a categorical exclusion would require either an EA or EIS. The EA will determine if the proposed action significantly affects the environment. If it does not, or the impacts can be mitigated below significant threshold levels, then a Finding of No Significant Impact (FONSI) is prepared. If the EA determines there are significant impacts, or the FAA anticipates significant impacts, then an EIS must be prepared. Once the NEPA process is completed, further review processes are also required to determine how a particular mitigation could be implemented, what other impacts could be (e.g. workload) and how it would be funded. This could further impact ease of implementation in near-term timeframes.

The potential system-wide impact of each mitigation was rated as Strong, Moderate or Weak depending on their relative impacts at the US system-wide (National Airspace System) level. So, for example, a mitigation that has potential to significantly reduce fuel burn in a given flight phase, but that phase is a small proportion of overall system fuel burn or could only be applied at a small number of locations would have a *Weak* or *Moderate* potential impact categorization. By contrast, a mitigation that was considered to have a relatively larger impact on total system fuel burn and/or could be applied widely would be ranked as *Strong*. Similar interpretations can be made for the other environmental impacts such as noise. For example, if a mitigation can significantly reduce noise, but it only applied at a small number of airports, it would be ranked as having a lower system-wide impact than a mitigation that could be applied much more widely within the system.

Through this process, the mitigations were systematically evaluated against common criteria. Classification according to the assessment criteria was subjective, but the process was refined and consensus built through several iterations within the research team, with the FAA and through further interaction with key stakeholders from the interview process. The results of this process are discussed next.

3. Results

The results of the operational mitigations assessment is shown in Table 2. For each, the qualitative assessment ranking consistent with the criteria discussed in the previous section is provided, along with a brief description of its characteristics and the rationale for the rankings.

From this process it is possible to compare mitigations and identify those most promising for further study and possible implementation. These generally have high system-wide impact potential coupled with relatively easy implementation in near-term timeframes.

3.1 Surface (S)

Surface operations account for a relatively small proportion of total system fuel burn, but a significant proportion of delay is incurred here and hence there are opportunities for meaningful environmental impact reductions. The qualitative assessment highlights that queue management systems hold potential to reduce fuel burn and emissions through better surface management, for example by absorbing as much delay as possible on the gate with engines off. Although technology-based queue management systems (S-1.2) are thought to offer the highest system-wide impact, they have non-trivial implementation barriers in terms of automation development and deployment which are likely to make near-term implementation a challenge. By contrast, more simple procedure-based systems (S-1.1) are considered likely to deliver moderate system-wide impact but with much easier implementation issues and hence they are considered good candidates for near-term mitigation. Harvesting ASDE-X surveillance data (S-2.4) would be a major contributor to the development of effective queue management systems and hence is also considered important for further study.

Hold or pass areas near runway ends (S-4.3) is considered to have a moderate system-wide impact potential but a medium implementation challenge due to the requirement for additional infrastructure at airports which may not be possible near-term. End-around taxiways to minimize runway and queue crossings (S-4.1) may have less system-wide impact but slightly easier implementation near-term, and hence these two mitigations are possible candidates for further study as a result.

Improved coordination tools (S-5) which enhance information sharing between ATC and operators are thought to have significant system-wide impact potential but also do not have easy implementability due to technical and stakeholder barriers which probably prevent new mitigations in these areas from being viable near-term opportunities.

The other surface mitigations were considered to have relatively weak system-wide impact potential. The taxi fuel minimization mitigations (S-2) are mostly considered easy to implement in the near-term and hence may be lower priority candidates for further study, as is ground power around the airport (S-6). The runway assignment mitigations (S-3) likely rely on some form of decision support for controllers to have any major impact, but this makes them harder to implement and hence lower priorities for near-term mitigation study.

3.2 Departure (D)

Engines typically operate at high thrust settings during take-off and departure operations, and hence mitigations in this phase can have significant fuel burn, emissions and noise impacts. Continuous climb (D-1.3) and maximum climb (D-1.6) departures are assessed to offer moderate system-wide impact with medium or easy implementability and hence may be appropriate for further examination.

Trajectories to minimize population noise exposure (D-1.5) offer strong system-wide impact for noise with medium implementability issues, but there are interesting adverse trade-offs with the other environmental metrics. Operating in the best noise configuration (D-1.10) has also been assessed to have strong system-wide potential for noise together with interesting trade-offs between noise benefits and possible adverse impacts for other metrics. Both of these mitigations would therefore warrant further study for these reasons. There are similar adverse impacts with optimal thrust cut-back (D-1.2), but this mitigation is considered to have a weak system-wide impact so is lower priority.

RNP/RNAV Enabled Standard Instrument Departure procedures (D-2.1) were determined to offer moderate system-wide impact for fuel and noise with medium ease of implementation. This type of procedure is being explored at a number of airports currently and hence a systematic assessment of their potential across the system would be highly valuable.

The other departure mitigations were ranked as having a weak system-wide impact and therefore are considered lower priorities for further study than the ones highlighted above.

3.3 Cruise (C)

The cruise phase of flight accounts for the largest proportion of total fuel burn, and hence mitigations here can have significant system-wide impacts. Therefore, many of the mitigations in this phase are worthy of careful consideration for further study for near-term implementation and these are detailed below.

Of the horizontal routing efficiency measures, Reduced Horizontal Separation Minima (C-1.1) and minimizing lateral route inefficiency (C-1.2) are considered to have strong system-wide benefit potential, but neither are considered easy to implement in the near-term (the former being ranked as hard and the latter as medium). In terms of vertical routing efficiency, Reduced Vertical Separation Minima (C-2.1) has good potential for environmental impact mitigation and has already been implemented in the US, so is excluded from further discussion here. Variants of cruise altitude optimization (cruise climb (C-2.3) and domestic step climb (C-2.4)) have significant mitigation potential with easy or medium implementation. Several speed efficiency measures also have strong or medium system-wide impact potential with moderate or easy implementation (cruise mach reductions (C-3.2)/more efficient passing options (C-3.3)).

Many of the other mitigations in the cruise phase hold promise, but were ranked as hard to implement and hence are not considered priorities for further study for near-term applications.

3.4 Approach (A)

The approach flight phase accounts for a relatively small amount of overall mission fuel burn because the engines are in low power settings for most of the descent, but there are fuel and noise savings to be gained during holding and final approach conditions. Optimal Profile Descents (A-1.1), steeper descent and approach (A-1.2), Low Power/Low Drag (A-1.3), RNP/RNAV enabled Standard Terminal Arrivals (A-1.4) and absorbing delay enroute instead of in the terminal area (A-3) are all assessed to have moderate system-wide impact with medium implementation challenges and hence are all worthy of further exploration for near-term system-wide implementation.

3.5 Landing (L)

The mitigations were assessed to have weak system-wide impact potential but relatively easy implementation in the near-term, so may be low priority candidates for further study.

3.6 Miscellaneous (M)

The improved airline/ATC coordination mitigations (M-2) all have moderate system-wide impact with most having medium ease of near-term implementation (a few are ranked as easy) and this is an area where further assessment is clearly warranted. Policy measures (M-3) have potential to have strong system-wide impact, but any mitigation involving policy change are unlikely to be realistic for near-term implementation. But given their impact potential, further study would clearly be useful for implementation in somewhat longer time timeframes.

4. Conclusions

This paper has discussed a research study to undertake a comprehensive identification and systematic evaluation of near-term operational changes to determine their relative environmental mitigation potential, as well as other factors such as barriers to implementation. Over 75 mitigations with the potential to reduce environmental impacts were identified based on a combination of literature review, aviation stakeholder interviews, and industry knowledge between the research team and the FAA project sponsors. In this paper, the 61 purely operational mitigations were discussed. The mitigations were qualitatively assessed in terms of their potential environmental benefit, ease of implementation and overall system-wide impact potential. Results for the operational mitigations identified have been presented in terms of their assessment rankings and what they mean in terms of which ones may be appropriate for further study and possible implementation.

One final point to note is that although the mitigations have been presented as independent, in reality there are important interdependencies. For example, absorbing delay en route instead of in the terminal area (A-3) relates to mitigations which change cruise speeds (C-3.1 and C-3.2) which are in turn related to enablers to making speed changes viable, such as more efficient passing options (C-3.3) and multi-laning (C-1.1). Such interdependencies affect the overall potential of each mitigation and this research can help identify these connections.

Table 2. Operational Mitigations Assessment (P=Primary; S=Secondary; 0=Neutral; A=Adverse). Note: the mitigation numbers may not be consecutive as the list contains only the pure operational mitigations.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
SURFACE								
S-1: Queue Management Systems								
S-1.1: Simple systems (procedure based)	S	S	S	S	Easy	Mod	Simple queue management strategies that modify the way existing surface operations are managed through basic procedural changes have potential for mitigating surface emissions. For example, keeping aircraft on the gate for longer can limit the buildup of queues on the airport surface and hence decrease taxi times, fuel burn and emissions.	**Secondary Fuel, Climate, Air quality, Noise:** Primarily developed for managing surface delay. Benefits of reduced taxi time lead to secondary fuel, climate, air quality and noise benefits; **Easy:** Do not require additional aircraft/ATC equipment or infrastructure additions, only simple changes to existing procedures; **Moderate:** Can be implemented at a wide range of airports but offers only modest fuel savings and noise reduction at each.
S-1.2: Complex systems (technology based)	S	S	S	S	Med	Strong	Queue management strategies that employ advanced technology to mitigate surface emissions by improving the overall efficiency of operations, reduce delay and taxi times, and hence increase the throughput of airports.	**Secondary Fuel, Climate, Air Quality, Noise:** Primarily developed for managing surface delay. Benefits of reduced taxi time lead to secondary fuel, climate, air quality and noise benefits; **Medium:** Requires additional equipment for ATC and some changes to existing procedures; **Strong:** Can be implemented at a wide range of airports with moderate impact at each.
S-2: Taxi Fuel Minimization								
S-2.1: Surface taxi route optimization	P	S	S	0	Easy	Weak	Assigning the shortest taxi path to departing or arriving aircraft to minimize taxi fuel burn.	**Primary Fuel:** Shortest taxi path motivated by saving taxi time and fuel; **Secondary Climate, Air Quality:** Reduced taxi fuel burn leads to secondary climate and air quality benefits; **Neutral Noise:** Noise impacts from taxiing aircraft are small to begin with, and reducing taxi time by a small amount with have little overall noise impact; **Easy:** Does not require any major policy or stakeholder changes and minimal technological improvements; **Weak:** Can be implemented at a wide range of airports, but overall fuel saving is small.
S-2.2: Single-engine taxi	P	S	S	0	Easy	Weak	This approach involves using less than the full complement of engines for taxiing. For twin-engine aircraft, this implies taxiing with a single engine operational. Using fewer engines for taxi results in a decrease in the total fuel burn.	**Primary Fuel:** Use of fewer engines to taxi is motivated by fuel saving; **Secondary Climate, Air Quality:** Reduced taxi fuel burn leads to secondary climate and air quality benefits; **Neutral Noise:** Uses fewer engines but at higher thrust on those operating, increasing noise per engine; **Easy:** Does not require any major policy or stakeholder changes and it has already been successfully implemented in the past; **Weak:** While these strategies can be implemented at a wide range of airports they offer only minimal fuel savings at each.
S-2.3: Operational tow-outs	P	S	S	S	Easy	Weak	Saves departure taxi fuel by towing aircraft out to departure runway using a tug. During departure tow-outs, the engines are not turned on until five minutes before takeoff (for warm-up). Aircraft emissions decrease, but tug emissions are introduced. This procedure is also known as dispatch towing.	**Primary Fuel:** Use of tugs is motivated by fuel saving; **Secondary Climate, Air Quality, Noise:** Reduced engine use for taxi leads to secondary climate, air quality and noise benefits; **Easy:** Does not require any major policy or stakeholder changes and has already been successfully implemented in the past. Need to have efficient way to return tugs to gate; **Weak:** While these strategies can be implemented at a wide range of airports they offer only minimal fuel savings at each.
S-2.4: Harvesting ASDE-X data	S	S	S	S	Easy	Mod	Airport Surface Detection Equipment-X (ASDE-X) is an airport surface surveillance system that provides aircraft and ground vehicle identification to ATC. It enables better queue management and improved surface situation awareness which may increase controller efficiency in managing taxiways and runways.	**Secondary Fuel, Climate, Air Quality, Noise:** Primarily developed for managing surface delay. Benefits of reduced taxi time lead to secondary fuel, climate, air quality and noise benefits; **Easy:** For airports already equipped with ASDE-X systems, analysing it does not require any major policy or stakeholder changes, has already been successfully performed for some airports; **Moderate:** Potential savings may be small at any given airport, but they can be implemented widely.
S-2.5: APU management	P	S	S	0	Easy	Weak	The APU generates power and conditioned air for aircraft on the surface when their engines are off. By better managing when and how the APU is used (e.g. by using ground power and air when available at a gate), fuel savings can be achieved.	**Primary Fuel:** Mitigation motivated by fuel saving; **Secondary Climate, Air Quality:** Reduced APU fuel burn leads to secondary climate and air quality benefits; **Neutral Noise:** APU not a major source of noise impacts; **Easy:** Has already been implemented; **Weak:** Can be implemented widely but offers only minimal fuel savings.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
S.3: Optimal Runway Allocation								
S-3.1: Assign departure runway to minimize taxi or airborne distance	S	S	S	0	Easy/ Med	Weak	Assigning aircraft to departure runways that gives the shortest ground taxi distance or time given the gate the aircraft is coming from, or assigning for minimum air distance given departure fix. Minimum taxi time may be different than minimum taxi distance when there is surface congestion.	**Secondary Fuel, Climate, Air Quality:** Developed primarily for surface or TRACON efficiency which minimizes taxi or TRACON distance and hence has secondary environmental benefits; **Neutral Noise:** Taxiing aircraft have minimal noise impact, airborne impact depends on population distribution relative to airborne path; **Easy/Medium:** Easy procedure-based if simply shortest distance, medium if automation needed to allocate for minimum time accounting for congestion; **Weak:** Can be implemented at a wide range of airports, but potential environmental benefit is small at each.
S-3.2: Assigning arrival runway closest to gate or w/ minimal air time	S	S	S	0	Easy/ Med	Weak	Assigning aircraft to arrival runways that gives the shortest air distance given arrival fix or ground taxi distance or time given the gate the aircraft is going to. Minimum taxi time may be different than minimum taxi distance when there is surface congestion.	**Secondary Fuel, Climate, Air Quality:** Developed primarily for surface or TRACON efficiency which minimizes taxi or TRACON distance and hence has secondary environmental benefits; **Neutral Noise:** Taxiing aircraft have minimal noise impact, airborne impact depends on population distribution relative to airborne path; **Easy/Medium:** Easy procedure-based if simply shortest distance, medium if automation needed to allocate for minimum time accounting for congestion; **Weak:** Can be implemented at a wide range of airports, but potential environmental benefit is small at each.
S-3.3: Preference to best runway for largest aircraft	P	S	S	0	Easy	Weak	Generally, larger aircraft have higher fuel burn and emissions rates than smaller aircraft. Therefore, when the largest aircraft is given priority to the best runways, fuel burn and emissions benefits should be seen.	**Primary Fuel:** Motivation for this mitigation is net fuel reduction; **Secondary Climate, Air Quality:** Reduced fuel use from big aircraft have secondary climate and air quality benefits; **Neutral Noise:** no clear impact on noise impacts; **Easy:** Simple procedure-based implementation; **Weak:** Can be implemented at a wide range of airports, but potential environmental benefit is small.
S-4: Improved Airport Taxiway Configurations								
S-4.1: End-around taxiways to minimize crossing queues	S	S	S	0	Med	Weak /Mod	Perimeter taxiways or end-around taxiways minimize active runway crossings during peak periods. Can enhance capacity/reduce delay by permitting uninterrupted takeoffs and landings on the runways.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is increased capacity/reduced delay, but this leads to secondary savings in fuel, climate and air quality impacts; **Neutral Noise:** Some reduced noise from aircraft delay reduction, but this is minimal and may be offset by more noise from taxiing aircraft using the end-around taxiway; **Medium:** Relies on some infrastructure addition; **Weak/Moderate:** Can be implemented at a wide range of airports, but potential environmental benefit depends on effectiveness in reducing delay at any given airport.
S-4.2: Improved locations of high-speed turn-offs to minimize taxi	S	S	S	0	Med	Weak/ Mod	If a runway exit is too close to the landing point, the speed of most aircraft will be too high to make the exit. In contrast, if the exit is too far down the runway, aircraft will have to extend their landing roll (increasing taxi time, runway occupancy time and possibly decreasing capacity) and may end up further away from the terminal area than necessary. Improved locations of high-speed turnoffs can reduce these effects, saving the airlines fuel and providing a potential air quality benefit. Moreover, because landing aircraft would be able to exit the runway sooner, aircraft queued for departure can depart sooner.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is increased capacity/reduced delay, but this leads to secondary savings in fuel, climate and air quality impacts; **Neutral Noise:** No obvious effect on noise; **Medium:** Relies on some infrastructure addition; **Weak/Moderate:** Can be implemented at a wide range of airports, but potential environmental benefit depends on effectiveness in reducing delay at any given airport.
S-4.3: Hold or pass areas near runway ends	S	S	S	0	Med	Mod	Hold or passing areas near runway ends allow re-sequencing of aircraft. This can maximize capacity of a runway by allowing optimized sequencing of flights as well as preventing an aircraft blocking a departure queue when it is unable to depart due to ATC constraints, equipment issues, weight delays, or other constraints.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is increased capacity/reduced delay, but this leads to secondary savings in fuel, climate and air quality impacts; **Neutral Noise:** No obvious effect on noise; **Medium:** Relies on infrastructure addition; **Moderate:** Can be implemented at a wide range of airports, and effectiveness at reducing delay at any given airport is likely to be larger than the other mitigations outlined above.
S-5: Improved Coordination Tools								
S-5.1: Improved info sharing & operator situational awareness tools	S	S	S	0	Med	Strong	Improving communication of unexpected congestion, downstream constraints and flight-specific data such EDCTs would allow more efficient handling of these events, increasing throughput and reducing delay.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is increased capacity/reduced delay, but this leads to secondary savings in fuel, climate and air quality impacts; **Neutral Noise:** No obvious effect on noise; **Medium:** Requires new tools and procedures; **Strong:** Could impact operator decisions across entire network.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
S-5.2: Flight plan change delivery over datalink	S	S	S	0	Med	Weak	During weather events, flight plan re-routes may not be finalized until the aircraft are near the front of the departure queue. Currently re-routes are done by voice which are slow and can create blocking in queues, leading to excess time and fuel burn for those aircraft behind. Datalink delivery could reduce some of these issues.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is increased capacity/reduced delay, but this leads to secondary savings in fuel, climate and air quality impacts; **Neutral Noise:** No obvious effect on noise; **Medium:** Requires new tools and procedures; **Weak:** More relevant at some airports than others. Relatively small number of times this mitigation would provide benefits system-wide.
S-6: Ground power for aircraft around airport	P	S	S	0	Easy/ Med	Weak	When aircraft have access to ground power, the pilot need not turn on the APU and hence could save fuel on the surface. If ground power was available at other locations, APU use would be lower still.	**Primary Fuel:** Motivated by APU fuel saving; **Secondary Climate, Air Quality:** Reduced fuel use has secondary climate and air quality benefits; **Neutral Noise:** APU is not a major source of noise; **Easy/Medium:** Making greater use of available ground power at gate, or adding additional units; **Weak:** Can be implemented at a wide range of airports, but potential environmental benefit is small at each.
DEPARTURE (D)								
D-1: Departure Procedures								
D-1.1: Intersection departures	0	0	0	0	Easy	Weak	Depart further down the runway than standard. Used to expedite traffic by saving time in taxi and departure queue. More engine power might have to be used than if the entire runway length was used in the takeoff.	**Neutral Fuel, Climate, Air Quality, Noise:** Offers limited fuel, emissions and noise savings because higher thrust might be required for a shorter runway takeoff; **Easy:** Does not require any extra equipment, technical development or stakeholder changes; **Weak:** Can be implemented at a wide range of airports, but potential benefits are small.
D-1.2: Optimal thrust cutback take-off	A	A	A	P	Easy	Weak	Thrust cutback take-offs are typically designed to get aircraft high quickly while inside and just outside the airport perimeter using maximum thrust at take-off, followed by a rapid decrease in engine power as the aircraft flies over noise sensitive locations close to the airport. Engine thrust is increased again when the noise sensitive location has been passed to continue the aircraft climb. Although these procedures are designed for noise abatement over specific locations, they also result in increased fuel burn and emissions at low altitudes.	**Primary Noise:** Motivated by noise reduction; **Adverse Fuel, Climate, Air Quality:** High thrust at low altitudes can increase fuel burn and emissions at low altitudes; **Easy:** Does not require any extra equipment, technical development or stakeholder changes. Already implemented in basic form; **Weak:** Adverse fuel, air quality, and climate impacts. Noise benefit per departure is small and restricted to the local airport and surroundings.
D-1.3: Continuous climb	P	S	S	S	Med	Mod	A continuous climb departure is a procedure that eliminates level segments as much as possible. The aim of this kind of departure is to get the aircraft out of the terminal area as quickly as possible, thus reducing the aircraft's noise footprint on the ground while also minimizing low altitude fuel burn and emissions.	**Primary Fuel:** Motivated by climb fuel reduction; **Secondary Climate, Air Quality, Noise:** Secondary benefits from emissions and noise reduction from spending less time at low altitudes; **Medium:** Requires changes to existing departure procedures; **Moderate:** Can be implemented at a wide range of airports, but with modest fuel and noise benefits.
D-1.4: Dispersal headings	S	S	S	S	Easy	Weak	Dispersal headings are often used to increase runway capacity by fanning flights out across the sky enabling use of smaller separations between successive departures from the same runway. Diverging course headings allow for reduced separation on departures, better runway utilization, and greater departure efficiency. Dispersal headings also spread the noise from departing aircraft over a wider area.	**Secondary Fuel, Climate, Air Quality, Noise:** Primarily designed to increase throughput, hence reducing delay resulting in secondary fuel burn, emissions and noise benefits; **Easy:** Does not require any extra equipment, technical development or stakeholder changes at airports where dispersal headings are available given airspace configuration; **Weak:** Some fuel, emissions and noise benefits when possible, but not applicable at many airports.
D-1.5 Trajectories to minimize population noise exposure	A	A	A	P	Med	Strong	Generation of a noise optimized departure given the population distributions, meteorological data, aircraft performance, navigation and airspace constraints.	**Primary Noise:** Mitigation is aimed at noise reduction; **Adverse Fuel, Climate, Air Quality:** Longer flight paths can result in greater fuel burn and emissions compared to a more direct departure trajectory; **Medium:** Currently used in some forms. Requires new procedure design and possible airspace modifications, but not any new aircraft technology; **Strong:** Can be implemented at a wide range of airports and offers noise reduction for all departure operations by equipped aircraft, but adverse effects likely to limit applicability.
D-1.6: Max-Climb Departures	S/A	S/A	S/A	P	Easy	Mod	Provide a priority departure route and unimpeded climb through to cruise altitude. Traditional 'step' departures are replaced with faster, more efficient flight profiles reducing noise impacts by getting aircraft to higher altitudes more quickly.	**Primary Noise:** Mitigation is aimed at noise reduction; **Secondary or Adverse Fuel, Climate, Air Quality:** Possibly offers secondary fuel and emissions savings due to more efficient initial climb, but could also increase low altitude fuel/emissions (see D-1.2); **Easy:** Does not require any major policy or stakeholder changes and has been successfully implemented in the past; **Mod:** Can be implemented at wide range of airports, but with modest fuel and noise benefits.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
D-1.8: Ensure use of entire runway	S	S	S	S	Easy	Weak	Using the entire runway length (i.e. not intersection or displaced departures) allows departing aircraft to get higher outside the airport perimeter, reducing noise. Alternatively, using more of the full runway length for the take-off roll permits greater use of lower (de-rated) engine thrust settings on take-off. This leads to maintenance cost savings, as well as to lower take-off fuel burn and emissions and lower engine noise, but may lead to a slower climb-out (which may increase noise impacts). Net noise effects would have to be explored further.	**Secondary Fuel, Climate, Air Quality, Noise:** Primarily useful for reducing engine maintenance costs. Offers limited secondary fuel, emissions and noise savings; **Easy:** Does not require any major changes; **Weak:** Can be implemented at a wide range of airports, but net noise and safety effects likely to be minimal.
D-1.9: Additional departure fixes	S	S	S	0	Med/ Hard	Weak	During departure, aircraft are typically routed to specific departure fixes which aid controllers in sequencing aircraft, while keeping them separated from the other departure and arrival flows. Additional departure fixes can add additional capacity at the TRACON boundary and serve as an alleviating factor for miles-in-trail (MIT) restrictions, which often slow down operations and increase delay.	**Secondary Fuel, Climate, Air Quality:** Primarily designed to increase capacity and reduce delay, which result in secondary fuel burn and emissions benefits; **Neutral Noise:** Surface noise impacts are negligible; **Medium/Hard:** Requires changes to airspace, departure procedures and possible new navaids; **Weak:** Cannot be implemented at all airports due to airspace constraints.
D-1.10: Operating in best noise configuration	0/A	0/A	0/A	P	Easy/ Med	Strong	Airport configuration and current weather determines which runways are used for arrival and departures, and hence airport capacity, which departure and arrival routes are in operation and which areas are being over-flown. Hence some configurations have lower environmental impacts than others.	**Primary Noise:** Mitigation is aimed at noise reduction; **Neutral or Adverse Fuel, Climate, Air Quality:** Configurations that minimize noise may require longer flight paths with increased fuel and emissions impacts. Also, best noise configuration may not have the highest capacity, potentially increasing delays and fuel use; **Easy/Medium:** Easy if simply operate in highest capacity configuration, Medium if technology needed to optimise configuration decision; **Strong:** Can be implemented at a wide range of airports and offers noise reduction for all departures.
D-2: Increased Flexibility in Departure Routes								
D-2.1: RNP/RNAV Enabled SIDs	P	P	S	S	Med	Mod	RNP/ RNAV Standard Instrument Departures enable aircraft to fly more precise and flexible departure trajectories potentially including fuel optimized climbs.	**Primary Fuel, Climate:** Reduces fuel use by enabling more precise and flexible departure trajectories nearer to optimum profiles; **Secondary Air Quality, Noise:** Most benefits at intermediate altitudes, but some low altitude reduced fuel burn and routing around noise sensitive regions have secondary air quality and noise impacts; **Medium:** Requires extra equipment and changes to existing departure procedures; **Moderate:** Potentially significant reductions which can be implemented at a wide range of airports.
D-2.2: Increased number of departure routes, multilaning	S	S	S	0	Med	Weak	Multi-laning, or adding multiple parallel routes to existing routes, is one opportunity to create additional capacity in the system. If done in ways consistent with controller structure-based abstractions, the cognitive complexity benefits should delay the onset of congestion. The increased precision of aircraft trajectories in RNAV and RNP operations provides opportunities to "multi-lane" existing flows through the addition of minimally spaced, laterally separated, routes. Adding multiple parallel routes to existing routes create additional capacity in the system and reduce ground delays. Combined with reductions in separation minima, parallel lanes can be deployed within the confines of the existing route structure.	**Secondary Fuel, Climate, Air Quality:** Primarily designed to increase airspace capacity and reduce delay which in turn offers secondary fuel, climate and air quality benefits. **Neutral Noise:** Impacts primarily at higher altitudes so noise impacts not significantly different; **Medium:** Requires extra equipment and changes to existing departure procedures; **Weak:** Cannot be implemented at all airports due to airspace constraints.
CRUISE (C)								
C-1: Horizontal Route Efficiency								
C-1.1: Reduced Horizontal Separation Minima (RHSM)	S	S	0	0	Hard	Strong	High navigational precision should eventually allow for RHSM, leading to higher capacity on an airway, and thus a reduction in inefficient spacing-related maneuvers. Could also enable "multi-laning", increasing capacity.	**Secondary Fuel, Climate:** Primarily motivated by increasing capacity/reducing congestion. Therefore, secondary fuel burn/emissions benefits; **Neutral Air Quality, Noise:** Applies during the cruise phase of flight at high altitudes so minimal air quality and noise effects; **Hard:** Requires significant changes to existing procedures, extra equipment, safety analysis; **Strong:** Can be implemented across the system with significant benefits possible.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
C-1.2: Minimize lateral route inefficiency	P	P	0	0	Med	Strng	The en-route flight environment consists of a network of airways that allow for simpler management of traffic flow by controllers. A set of defined waypoints is used to map these airways. By giving each aircraft more authority in its navigation, aircraft can fly more direct routes, saving fuel burn and potentially avoiding traffic congestion on airways.	**Primary Fuel, Climate:** Reduces cruise fuel burn and emissions by reducing total distance flown; **Neutral Air Quality, Noise:** Applies during the cruise phase of flight at high altitudes so minimal air quality and noise effects; **Medium:** Requires changes to existing procedures and current routes but no extra equipment; **Strong:** Can be implemented at high altitudes across the NAS.
C-1.3: 3D/4D trajectory with minimal changes	P	P	0	0	Hard	Mod	3D trajectories include lateral and vertical, while 4DTs specify target times at specific waypoints. Currently pilots are given many trajectory change commands, like speed or altitude changes, which cause inefficiency. By planning these trajectories in advance, traffic flow can be optimized before flights begin. Using the full potential of these trajectories ensures there is no unnecessary holding due to unforeseen capacity limitations or weather en route or at the destination.	**Primary Fuel, Climate:** Reduces cruise fuel burn/emissions by minimizing ATC-commanded flight plan changes and allowing an optimized flight plan t be followed as closely as possible; **Neutral Air Quality, Noise:** Applies during the cruise phase of flight at high altitudes so minimal air quality and noise effects; **Hard:** Requires NextGen 4DT capability; **Moderate:** Can be implemented across the NAS, but total benefit unclear.
C-1.4: Increased sector size	S	S	0	0	Hard	Weak	Airspace is divided into sectors that define the boundaries of controller authority. Special protocols must be established to ensure proper handoff of aircraft between sectors requiring aircraft to navigate to specific hand-off points between sectors. In addition, neighboring controllers must coordinate with each other to confirm each handoff. These procedures are workload intensive and may require inefficient routing. A reduction in airspace fragmentation could reduce the number of sector changes required during a flight, thus increasing route efficiency and reducing fuel burn and emissions.	**Secondary Fuel, Climate:** Primary motivation is reduced inefficiency which leads to secondary cruise fuel burn/emissions savings; **Neutral Air Quality, Noise:** Applies during the cruise phase of flight at high altitudes so minimal air quality and noise effects; **Hard:** Requires redesign of the airspace; **Weak:** Can be implemented across the NAS, but potential environmental benefit is probably small.
C-2: Vertical Routing Efficiency								
C-2.1: Reduced Vertical Separation Minima (RVSM)	S	S	0	0	Easy	Strong	Reduces the vertical separation of flights above FL290 from 2000 ft to 1000 ft. Each flight level is reserved for either east or westbound traffic, and the directions alternate, so in areas where RVSM is not in place, same direction traffic is separated by 4000 ft (as compared to 2000 ft with RVSM). Thus RVSM allows aircraft to fly closer to their optimal altitude and increases flow capacity, reducing inefficient separation maneuvers.	**Secondary Fuel, Climate:** Primary motivation is increased capacity in cruise sectors, which reduces congestion and hence has secondary fuel burn and emissions benefits; **Neutral Air Quality, Noise:** Applies during the cruise phase of flight so minimal air quality and noise effects; **Easy:** Currently implemented and does not require any alterations to existing procedures or equipment; **Strong:** Can be (and is currently) implemented at high altitudes across the NAS
C-2.2: Increased directional airways	P	P	0	0	Med	Mod	Using uni-directional airways allows same-direction traffic to be separated by 1000 ft, as compared to 2000 ft for standard bi-directional airways under RVSM (see C-2.2). This allows aircraft to fly closer to their optimum altitude, but may also reduce lateral efficiency if additional airways needed for opposite direction flows (unless multi-laning is also applied).	**Primary Fuel, Climate:** Primary motivation is allowing aircraft to fly closer to their optimum altitude, reducing fuel burn and emissions; **Neutral Air Quality, Noise:** Applies at high altitudes so minimal air quality and noise effects; **Medium:** Requires changes to existing airspace but no extra equipment; **Moderate:** Potential for big impacts from fuel reduction due to improved vertical efficiency, but may be offset by possible reduced lateral efficiency.
C-2.3: Cruise climb	P	P	0	0	Med	Strng	Most domestic flights are flown at a single cruise altitude to minimize pilot and controller workload associated with changing cruise altitudes to get closer to the optimum level. Cruise climb is closer to the ideal trajectory consisting of a slow, relatively linear climb as the aircraft weight decreases as fuel is burned.	**Primary Fuel, Climate:** Mainly aimed at reducing fuel burn and emissions by allowing aircraft to fly at their ideal altitude at all times; **Neutral Air Quality, Noise:** Applies during the cruise phase of flight at high altitudes so minimal air quality and noise effects; **Medium:** Requires changes to existing procedures and current routes but no extra equipment; **Strong:** Significant benefits possible if implemented.
C-2.4: Domestic step-climb	P	P	0	0	Easy	Mod	Similar to cruise climbs, except instead of a continuous smooth climb, the aircraft climbs to discrete altitude levels periodically and then flies at that constant altitude until the next climb is warranted. Requires ATC coordination at each step and is less efficient than the continuous cruise climb, but more efficient than a single constant altitude cruise.	**Primary Fuel, Climate:** Mainly aimed at reducing fuel burn and emissions by allowing aircraft to fly close to their ideal altitude at all times; **Neutral Air Quality, Noise:** Applies at high altitudes so minimal air quality and noise effects; **Easy:** Can be done now with existing equipment, may need some minor ATC procedure modifications; **Moderate:** Less efficient than continuous cruise climbs, but far more efficient than a constant altitude cruise.
C-2.5: Increase priority for requested/optimal altitudes	P	P	0	0	Med	Mod	Aircraft are typically rerouted and given altitude assignments to expedite the overall flow through the airspace, while maintaining a high level of safety. It may be possible to increase the frequency with which the closest to ideal altitude would be granted to pilots without compromising safety/throughput.	**Primary Fuel, Climate:** Mainly aimed at reducing fuel burn and emissions by allowing aircraft to fly closer to their ideal altitude more of the time; **Neutral Air Quality, Noise:** Applies at high altitudes so minimal air quality and noise effects; **Medium:** relatively easy to implement with political will, but requires shift in ATC policies; **Moderate:** Benefits not as much as routine continuous or step climbs.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
C-3: Speed Efficiency								
C-3.1: Individual aircraft fuel-optimized cruise speeds	P	P	0	0	Hard	Strng	Airline priorities often dictate that aircraft fly faster than their best fuel speed (e.g. to maintain schedule). Also, ATC assigns aircraft common speeds to aid in their management of traffic flows.	**Primary Fuel, Climate:** Permitting each aircraft to fly at its minimum fuel burn speed would allow for reduced fuel burn; **Neutral Air Quality, Noise:** Applies at high altitudes so minimal air quality and noise effects; **Hard:** Requires extra equipment, safety analysis, changes to existing procedures and ATC coordination; **Strong:** Could have significant benefits on total fuel use and emissions if implemented.
C-3.2: Cruise Mach reductions	P	P	0	0	Easy	Mod	Individual aircraft speeds (C-3.1) creates the problem of traffic conflicts along single-lane airways, so controllers usually command a common speed. If ATC instead reduced the speed along airways by the same amount for all aircraft, most aircraft would be closer to their best economy speed, reducing fuel burn.	**Primary Fuel, Climate:** Motivated by reduction of fuel burn and emissions; **Neutral Air Quality, Noise:** Applies at high altitudes so minimal air quality and noise effects; **Easy:** Simple change to existing procedures, but possibly undesirable for other stakeholders; **Moderate:** Less benefit than all aircraft at optimal speed, but still significant savings if implemented widely.
C-3.3: More efficient passing options	P	P	0	0	Med	Strng	Aircraft flying on the same airway at significantly different speeds require a passing maneuver. These are often inefficient, e.g. in terms of extra distance. More efficient passing options could minimize extensive reroutes or speed changes, while being an enabler to more efficient cruise speed allocation (see C-3.1 and C-3.2).	**Primary Fuel, Climate:** Enabler to permitting each aircraft to fly at its minimum fuel burn speed; **Neutral Air Quality, Noise:** Applies at high altitudes so minimal air quality and noise effects; **Hard:** Requires extra equipment, safety analysis, changes to existing procedures and ATC coordination; **Strong:** Could have significant benefits on total fuel use and emissions if implemented.
C-4: Contrail minimization	A	P	0	0	Hard	?	Contrails are thought to have a warming effect on the climate. If conditions under which they form (related to the relative humidity and temperature of the plume relative to ambient conditions) can be accurately forecast, their formation can be avoided.	**Primary Climate:** Avoiding suspect regions reduces any climate impacts of contrails, but net effects unclear once emissions from possible adverse fuel burn are included; **Adverse Fuel:** Avoidance would likely involve longer flight paths or off-optimal altitudes, causing increased fuel burn; **Neutral Air Quality, Noise:** Applies at high altitudes so minimal air quality and noise effects; **Hard:** Forecasting contrail-forming regions is challenging, avoiding them is easy if known; **?:** Improvements in forecast ability needed, as well as understanding of the global warming impact of contrails.
C-5: Polar routing minimization	A	P	0	0	Easy	?	Emissions in polar regions are thought to have a larger environmental impact than the equivalent emissions outside this region. Minimizing aircraft travel through polar regions could potentially reduce these effects, but would result in higher fuel burn.	**Primary Climate:** Avoiding the sensitive polar climate could reduce overall adverse climate impacts; **Adverse Fuel:** Avoidance procedures involve longer flight paths, causing increased fuel burn, so net benefits unclear; **Neutral Air Quality, Noise:** Applies during cruise flight at high altitudes; **Easy:** Rerouting flights is done routinely now; **?:** Improved understanding of the local and overall climate effects of polar routings is needed.
APPROACH (A)								
A-1: Advanced Approach Procedures								
A-1.1: Optimal Profile Descents (OPD)	P	P	P	P	Med	Mod	An arrival procedure with vertical profiles optimized to facilitate a continuous descent approach from top of descent to touchdown. Keeps aircraft higher and at lower thrust for longer than conventional techniques by eliminating level flight segments using capabilities of the aircraft FMS.	**Primary Fuel, Climate, Air Quality, Noise:** Original primary motivation was noise reduction. Now OPDs optimize from higher altitudes to gain fuel/emissions benefits too; **Medium:** Successfully implemented at some airports, but airspace changes needed for wide implementation; **Moderate:** Fuel burn relatively low in approach phase, limiting total possible benefit, noise savings can be significant if widespread implementation possible.
A-1.2: Steeper descent & approach	S	S	S	P	Med	Mod	Increasing the descent rate in the terminal area keeps the aircraft at higher altitudes a given distance from the airport which will reduce community noise. Further, if a steeper approach could be achieved without noise penalty and without compromising flight safety, then aircraft could land at airports with limited access.	**Primary Noise:** Mainly aimed at decreasing noise around airports; **Secondary Fuel, Climate, Air Quality:** Offers only limited fuel savings during a short phase of flight; **Medium:** New/modified technical infrastructure (e.g. ILS) & safety measures may be required; **Moderate:** Can be implemented at a wide range of airports.
A-1.3: Low Power/Low Drag (LP/LD)	P	P	P	P	Med	Mod	Keeps aircraft speed higher for longer than a conventional approach and hence in a cleaner aerodynamic configuration with associated lower drag, fuel burn and noise.	**Primary Fuel, Climate, Air Quality, Noise:** Can be designed to improve fuel burn, emissions and noise performance; **Medium:** No extra equipment is needed, but ATC procedure changes may be required, possible impact on throughput; **Moderate:** Can be implemented at a wide range of airports but ATC procedures may need to be modified to handle the higher aircraft speeds.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
A-1.4: RNP/RNAV Enabled STARs	P	P	S	S	Med	Mod	Enable aircraft to fly more precise and flexible arrival trajectories closer to the optimal procedures.	**Primary Fuel, Climate:** Reduces fuel use by enabling more precise and flexible departure trajectories nearer to optimum profiles; **Secondary Air Quality, Noise:** Most benefits at intermediate altitudes, but some low altitude reduced fuel burn and routing around noise sensitive regions have secondary air quality and noise impacts; **Medium:** Requires extra equipment and changes to existing departure procedures; **Moderate:** Potentially significant reductions which can be implemented at a wide range of airports.
A-2: Reduced go-arounds	S	S	S	S	Hard	Weak	Go-arounds are executed when a pilot aborts an approach, which can be caused by factors such as poor weather conditions, insufficient separation with preceding aircraft, etc. Go arounds require aircraft to re-enter the approach pattern, causing additional fuel burn, emissions and noise.	**Secondary Fuel, Climate, Air Quality, Noise:** Reduced go arounds would primarily be a safety benefit. If reduction in the number of go-arounds could be achieved, fuel, emissions and noise benefits would be a secondary benefit; **Hard:** Go arounds occur for unpredictable reasons and hence reducing them would be a complex task; **Weak:** Many go-arounds are safety related and cannot be avoided. The small number than can be avoided would have a minimal effect on environment.
A-3: Absorbing delay enroute instead of terminal area	P	P	S	S	Med	Mod	If terminal area delays were known in advance, it would be more efficient to absorb the delays at high altitude in cruise (e.g. by small speed reductions or track extension in cruise) where engines are more efficient compared to in the terminal area.	**Primary Fuel, Climate:** Mainly aimed at reducing fuel use and emissions by absorbing delay in a more efficient way at cruise; **Secondary Air Quality, Noise:** Reduced delay in the terminal area would eliminate some lower altitude emissions and noise impacts; **Medium:** Requires procedures & tools to support controllers to predict delay in advance and then coordinate between en route and terminal controllers; **Moderate:** Delay is being moved to more efficient flight regime rather than eliminated, but mitigation could be implemented at a wide range of locations.
LANDING (L)								
L-1: Displaced landing thresholds	0	0	0	P	Easy	Weak	A displaced threshold is a landing threshold located at a point further down the runway than the standard. This helps raise the altitude of arriving aircraft outside the airport perimeter and reduces noise impacts as a result.	**Primary Noise:** Increases altitude over surrounding area to reduce noise impact; **Neutral Fuel, Climate, Air Quality:** The flight profile is identical, so no changes in fuel or emissions; **Easy:** Landing further down the runway requires no extra capability as long as the runway is long enough for the aircraft. Possible need for additional infrastructure, such as ILS for displaced threshold; **Weak:** Altitude gained by displacement is marginal and has only a small noise impact.
L-2: Reduced thrust reverser usage	S	S	S	P	Easy	Weak	Thrust reversal shortens landing distance and improves the throughput of airports by allowing aircraft to clear the runway faster. However, associated engine thrust increase causes more noised and fuel burn on landing, so reduced thrust reverse has benefits in these areas.	**Primary Noise:** Reduction in noise around the airport is the primary reason for mitigation; **Secondary Fuel, Climate, Air Quality:** Reduces fuel use and emissions during landing roll; **Easy:** Most aircraft can land without needing thrust reversers in today's system, so this would be a simple procedure change; **Weak:** The noise reduction only impacts the area immediately surrounding the airport, and the fuel and emissions effect is small.
L-3: Reduced flap landing	P	P	P	P	Easy	Weak	When conditions are appropriate (e.g. long runway, good weather conditions), landing at less than full flap settings is possible. This reduces drag and hence fuel burn. The highest flap setting can generate more drag than lift. Reduced flap landings will not only reduce fuel consumption but also decrease noise and emissions.	**Primary Fuel, Climate, Air Quality, Noise:** Less flap usage reduces drag, which reduces fuel burn, emissions and airframe noise at low altitudes; **Easy:** Requires no extra capability as long as runway conditions allow; landing speed would be increased somewhat so possible impacts on approach procedures and throughput; **Weak:** Actual impacts are small and only affect a very short portion of the flight.
MISCELLANEOUS (M)								
M-1: Aircraft Efficiency								
M-1.6: Reduced use of air conditioning packs	P	S	S	0	Easy	Weak	Air conditioning packs are often used at the gate to cool the aircraft interior. The packs can be powered by the aircraft APU or ground power unit. Reduced use of the packs through other cooling means (e.g. closing window shades at the gate) or by powering packs from ground power sources will reduce aircraft fuel burn.	**Primary Fuel:** Mitigation motivated by fuel saving; **Secondary Climate, Air Quality:** Reduced APU fuel burn leads to secondary climate and air quality benefits; **Neutral Noise:** APU not a major source of noise impacts; **Easy:** Does not require any major policy or stakeholder changes and it has already been successfully implemented in the past; **Weak:** Can be implemented at a wide range of airports but offers only minimal fuel savings at each.

Mitigation	Fuel	Climate	Air Quality	Noise	Implement	System Impact	Description	Rationale
M-2: Improved Airline/ATC Coordination								
M-2.1: Airborne flow program	S	S	S	0	Easy	Mod	FAA initiative to improve flight-planning coordination between airlines and ATC. Participating aircraft would coordinate their flight plan with ATC and receive clearance through otherwise constrained airspace. Offers opportunity to avoid expensive delays or re-routing by essentially reserving a slot for their preferred route.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is improved airspace efficiency and delay reduction with resulting secondary fuel and emissions savings; **Neutral Noise:** No obvious noise impacts; **Easy:** Currently used in some form; **Moderate:** Can be implemented across the system but total benefits only moderate.
M-2.2: Increased use of TMA or similar tools	S	S	S	0	Easy	Mod	TMA allows for optimized trajectories that a controller would not otherwise be able to provide manually. Increased use of these tools can increase the routing efficiency of many flights, thus reducing fuel burn as well as reducing emissions in the terminal environment.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is improved airspace efficiency and delay reduction with resulting secondary fuel and emissions savings; **Neutral Noise:** No obvious noise impacts; **Easy:** Currently used in some form; **Moderate:** Can be implemented across the system but total benefits only moderate.
M-2.3: Integrated CDM/TFM solutions	S	S	S	0	Med	Mod	Takes advantage of increased coordination between aircraft operators and ATC to achieve better planning and more efficient flight operations.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is improved airspace efficiency and delay reduction with resulting secondary fuel and emissions savings; **Neutral Noise:** No obvious noise impacts; **Medium:** Requires policies to facilitate improved airline/ATC coordination & advanced software tools; **Moderate:** Can be implemented across the system but total benefits only moderate.
M-2.4: Improved ATC predictability to reduce contingency fuel	P	P	S	S	Med	Mod	Excess fuel is carried by aircraft accommodate operational uncertainties, such as re-routes or airborne holding. If ATC's intentions and constraints are made more widely known and understood, aircraft can better plan for flight plan deviations.	**Primary Fuel, Climate:** Primary motivation of mitigation is to reduce excess weight of aircraft and hence total fuel burn and emissions; **Secondary Air Quality, Noise:** Reduced weight of aircraft leads to lower take-off thrust and hence low altitude emissions and noise; **Medium:** Dispatchers can easily change how flights are planned, but more accurate information from ATC is required for forecasting which would require new technology; **Moderate:** Changes to most flights may be small, but has potential to improve system fuel burn.
M-2.5: Information sharing tools (SWIM)	S	S	S	0	Med	Mod	Concept to centralize information sharing over the NAS. Currently, data is derived from various parties, including ATC, weather stations, airlines, airports, etc., and is distributed via radio, internet, and by other means. SWIM integrates these information sources into a central hub, where anyone can connect and get the same up to date information. Enables more optimal flight planning, saving fuel burn and emissions.	**Secondary Fuel, Climate, Air Quality:** Primary motivation is improved airspace efficiency and delay reduction with secondary fuel and emissions savings; **Neutral Noise:** No obvious noise impacts; **Medium:** Requires development of new technologies and procedures to take advantage of new functionality; **Moderate:** Can be implemented across the system but total benefits may be only moderate.
M-2.6: Special activity airspace real-time status & scheduling	P	P	0	0	Hard	Mod	Accurate fuel planning and optimum flight path routing requires known availability of the relevant airspace. Special activity airspace operated by the military is often closed or its status is unknown, requiring operators to plan around that airspace. Tighter coordination between ATC, operators, and authorities in charge of this airspace could enable scheduling aircraft through the airspace during times when it is not in use.	**Primary Fuel, Climate:** Primary motivation is to allow better flight planning through available airspace to minimize fuel burn and emissions; **Neutral Air Quality, Noise:** Benefits are obtained only at high altitudes during the cruise phase of flight; **Hard:** Disclosure of special-use airspace activity might face resistance from primary users of that airspace; **Moderate:** Could offer significant benefits on applicable routes, but number of routes affected is limited.
M-2.7: ICAO changes to increase info available to ATC from flight plan	S	S	0	0	Med	Mod	ICAO has considered adding information in its flight plan format that would allow for more detailed equipage, route, and altitude information. This expansion could allow pilots and airlines to request paths that optimize routing and altitude efficiency which optimize fuel burn	**Secondary Fuel, Climate:** Giving more detailed information in flight plan enables ATC to better understand needs and capabilities of a given flight, making more efficient handling possible with associated fuel and emissions savings; **Neutral Air Quality, Noise:** Applicable mostly to the cruise segment of flight at higher altitudes; **Medium:** It is unclear how easy adoption of a new flight plan format would be; **Moderate:** Opportunity to file and communicate preferred routes for all flights, but other system constraints could still prevent them from being available to an aircraft.
M-3: Policy Measures								
M-3.2: Increase ATC priority for environmental performance	P	P	P	P	Hard	Strng	In addition to the primary safety objective, ATC prioritizes maximizing system throughput and does not explicitly consider or measure environmental performance. If new policies and training can be implemented to emphasize the importance of accommodating environmental performance (and provides guidance on what options are available) gains could be made.	**Primary Fuel, Climate, Air Quality, Noise:** Motivated by benefits in all environmental performance areas; **Hard:** Requires extensive changes to existing policies and procedures for ATC without adversely impacting other key performance metrics; **Strong:** If implementable, could produce benefits across system.

Mitigation						Description	Rationale
Fuel	Climate	Air Quality	Noise	Implement	System Impact		
M-5: Airspace Redesign to Increase Efficiency						Current airspace and corresponding procedures are generally designed for capacity and not environmental performance. Redesigning airspace to avoid sensitive areas, shorten routing, etc., would help lay the groundwork needed for a more environmentally-friendly airspace system.	**Primary Fuel, Climate, Air Quality, Noise:** Motivated to design airspace to accommodate better environmental performance across all areas; **Hard:** Could require extensive changes to existing airspace; **Strong:** Radical airspace redesign offers benefits in fuel, climate, air quality and noise, on a system-wide level.
P	P	P	P	Hard	Strng		
M-6: Integrating terminal and en route control facilities						Reduces inefficient interfaces and possible competing objectives between control facilities.	**Secondary Fuel, Climate:** Primary motivation is improved airspace efficiency, resulting in secondary fuel burn and emissions benefits; **Neutral Air Quality, Noise:** No obvious low altitude impacts; **Hard:** Major re-design of ATC; **Moderate:** While potentially impacting many flights, the overall performance gains may only be moderate.
S	S	0	0	Hard	Mod		

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