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Preliminary Investigation of Sector Tools Descent Advisory Potential Benefits

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Executive Summary

Researchers at the NASA Ames Research Center have proposed a system based on an extension of the Center/TRACON Automation System (CTAS) to facilitate “free flight”. One component, a sector tool, manages traffic through transitions and other constraints within and between Air Route Traffic Control Centers (ARTCCs). The sector tool supports en route controllers by generating accurate, fuel-efficient clearance advisories for the merging, sequencing, and separation of high-density traffic. It also provides automation assistance for the prediction and resolution of conflicts between aircraft in all phases of flight. This tool enables controllers to implement more direct aircraft routes and descents without compromising safety.

This is a preliminary investigation to determine rough-order-of-magnitude (ROM) benefits resulting from optimized descents and direct routes into the TRACON. Flight efficiency of optimal and baseline descent trajectories were analyzed to determine fuel savings available with the sector tool. Aircraft performance simulations that model aircraft trajectories and fuel burn were used to determine the efficiency of B73S and DC10 aircraft trajectories. In this investigation initial and final conditions of each trajectory as well as flight time were fixed. The potential benefits from three optimization scenarios were considered in this investigation: vertical profile optimization, use of anchor points, and direct routing.

The vertical profile optimization mechanism affects the vertical plane dynamics of an aircraft descent or ascent trajectory. This investigation focuses on descent trajectories from cruise to the metering fix altitude. The sector tool is used to move the TOD location downstream to keep the aircraft at the more fuel efficient higher altitude as long as possible. Positioning of the TOD location is constrained by the location of the bottom of descent at the metering fix. The steepest descent profile corresponds to the optimal idle-thrust descent.

The anchor point mechanism also affects the vertical plane dynamics of an aircraft descent trajectory by attempting to minimize aircraft flight time at low altitude. The sector tool can provide detailed traffic information that will allow a controller to safely direct an aircraft to a new bottom of descent, called the anchor point, downstream of the metering fix. This anchor point enables aircraft to spend a greater proportion of total flight time at the more fuel efficient higher altitudes.

The direct routing mechanism attempts to improve efficiency by changing the horizontal plane dynamics of the aircraft trajectory. Direct routing shortens the actual path length flown by “cutting the corner” to eliminate indirect routes or “dog-legs”.

A weighted estimate of fuel savings per flight was calculated for arrivals based on fleet mixes at the Dallas-Fort Worth airport. The results were then extrapolated to the national level by assuming that the sector tool benefits are applicable to carrier and air taxi operations at each of 67 focus airports spanning the contiguous United States. The following table summarizes the results.

Benefit Mechanism	**Estimated National Annual Savings (1997 $ Millions)**			
		Maximum		**Expected**
	Simulation Condition	**Per Flight (lb)**	**Maximum ($ Millions)**	**ROM Estimate ($ Millions)**
TOD Optimization	2.5°	0 - 223	150.9	33.7
Anchor Point	10 nm	0 - 138	46.7	41.7
Direct Routing	60°	0 - 1018	689.1	30.8

National Total		0 - 1379	886.7	**106.2**

1 Introduction

Researchers at the NASA Ames Research Center have proposed a system based on an extension of the Center/TRACON Automation System (CTAS) to facilitate “free flight” [1]. This concept consists of two components. The first, an airspace tool, reduces controller workload by handling unconstrained en route aircraft. The second, a sector tool[1], manages traffic through transitions and other constraints within and between Air Route Traffic Control Centers (ARTCCs). This study investigates potential benefits of the sector tool.

The sector tool supports en route controllers by generating accurate, fuel-efficient clearance advisories for the merging, sequencing, and separation of high-density traffic. The sector tool also provides automation assistance for the prediction and resolution of conflicts between aircraft in all phases of flight [1]. This tool enables controllers to implement more direct aircraft routes and descents without compromising safety. Potential fuel savings benefits resulting from optimized descents and direct routes into the TRACON are the focus of this report.

This is a preliminary investigation to determine rough-order-of-magnitude (ROM) benefits to determine if more a detailed analysis is warranted. This report establishes sensitivities of the various sector tool benefit mechanisms. Actual distributions for the use of these mechanisms are subjects for later work.

The scope of this work is limited to evaluating potential benefits of three mechanisms of the sector tool assuming 100% efficiency and applicability of the mechanisms. Flight efficiency was analyzed to determine fuel savings available with the sector tool. Analysis of flight time and delay reduction benefits were not in the scope of this investigation.

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[1] The sector tool was formerly know as the Descent Advisor. A draft documenting the concept and evolution of the sector tool is under development by Steve Green, NASA Ames Research Center.

2 Background

The purpose of the sector tool is to provide controllers with the tools to (i) integrate conflict resolution with air traffic management constraints and (ii) facilitate intersector coordination. The sector tool can determine efficient aircraft ascent and descent trajectories while meeting constraints such as prescribed bottom of descent location, top of climb location, arrival time, altitude and airspeed. The sector tool also detects and helps avoid conflicts. Through its ability to evaluate provisional situations, the sector tool predicts the effect of a plan before it is implemented. These features give en route controllers the flexibility and confidence to direct aircraft more efficiently while meeting separation requirements and other constraints where, currently, they may be issuing conservative advisories resulting in less efficient trajectories.

Use of the sector tool reduces en route controller workload, allowing the controllers to focus on efficiency as well as safety. The potential benefits from three optimization scenarios were considered in this investigation. These are vertical profile optimization, use of anchor points, and direct routing. The potential benefits of each of these mechanisms were determined using generic flight plans and trajectories.

2.1 Vertical Profile Optimization

Descents

Continuous descent profiles are preferable to step[2] descent profiles because of their improved fuel efficiency. One method of comparing descent efficiency is by varying the top of descent (TOD)[3] without changing the final conditions of the flight plan. For this investigation the vertical profile of descents will be optimized by varying the TOD location. This is referred to as TOD optimization.

The different TOD locations can be realized with a series of trajectories with constant flight path angles. These constant–γ trajectories can be used to represent the average characteristic flight path angles of step descents. Sorensen and Shen [2] studied the fuel consumption for these trajectories and their results are presented later in this report. Figure 2.1 illustrates aircraft descent trajectories from cruise to the metering fix altitude. As the TOD location is moved downstream, the flight path angle, γ, becomes steeper, as shown in Figure 2.1.

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[2] A step descent profile may consist of one or more descent segments separated by level flight segments. Air traffic controllers may use step descents to ensure conflict avoidance.

[3] The TOD is the location at which the aircraft begins to descend in altitude from its cruise flight level. In this investigation, the bottom of descent corresponds to a metering fix or anchor point.

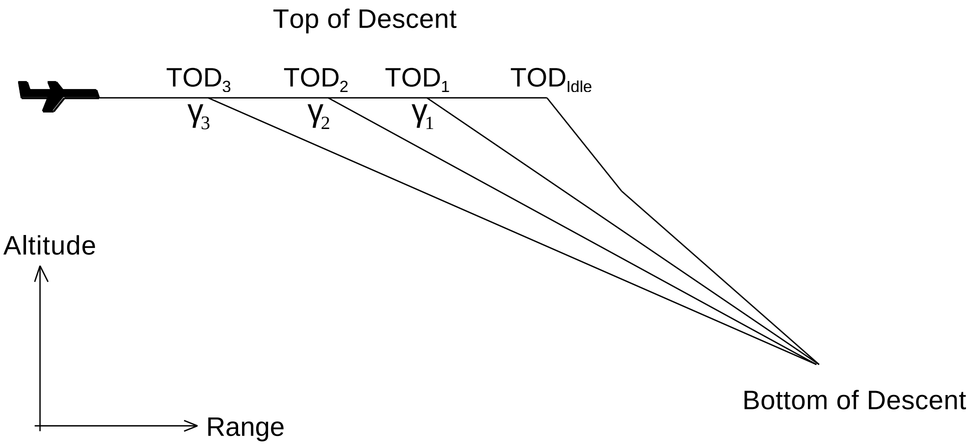

Figure 2.1 Illustration of constant-γ descents compared to an idle-thrust descent.

The baseline for this study is the idle-thrust descent trajectory. Since it is considered to be the optimal descent path [3], it serves as the preferred path to which the others are compared. Note that the trajectory of an idle-thrust descent does not have a constant flight path angle, as shown in Figure 2.1. Continuous descents, supported by the sector tool, are alternatives to conservative, less fuel efficient step descent trajectories.

Ascents

Similarly to TOD optimization, the top of climb location may be optimized to improve fuel efficiency of ascent trajectories. Although the sector tool is available to assist in optimizing vertical ascent profiles, top of climb optimization is not in the scope of this investigation.

2.2 Anchor Points

Aircraft entering a TRACON are currently being directed by en route controllers to arrive at metering fixes which are approximately 30 nautical miles (nm) from the runway threshold. Aircraft typically cross metering fixes at an altitude of 10,000 feet (ft) and an airspeed of 250 knots (kt). A potential benefit of the sector tool is that it can provide detailed traffic information that will allow the controller to safely direct an aircraft to a new bottom of descent downstream of the metering fix. This allows aircraft to spend more time at the more fuel efficient higher altitudes. Figure 2.2 illustrates this anchor point.

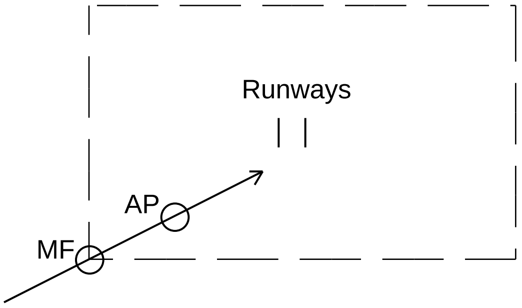

Figure 2.2 An anchor point (AP) serves the same purpose as a metering fix (MF) but is located downstream to minimize aircraft time at low altitudes.

The obvious benefit of an anchor point is the decreased fuel consumption resulting when the flight time at low altitude is reduced. This concept may be expanded to specify individual anchor points to accommodate differences in performance between various types of aircraft. These anchor points may be defined by a point in space or an airspeed. Only position is considered in this investigation.

A second benefit of an anchor point is that an aircraft can shorten its path by flying directly to the point instead of through the metering fix. Figure 2.3 shows how an anchor point can reduce the distance that the aircraft must travel.

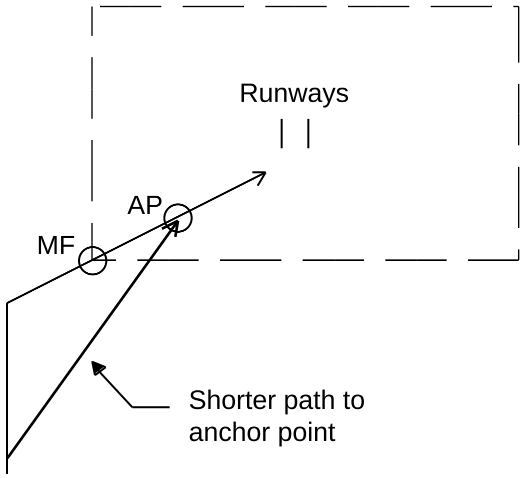

Figure 2.3 Use of an anchor point can reduce the path length.

The shorter path length can be beneficial in two ways. If a time of arrival at the anchor point must be met, the time saved by the reduced distance can be absorbed with a reduction in the airspeed, resulting in reduced fuel consumption. The time savings can alternatively be used to save direct operating costs. This report focuses on the fuel savings benefit. This path shortening scenario is similar to direct routing, discussed in the next section.

Anchor point benefits may be more significant for long-side arrivals both because of the additional cruise length to be gained and greater potential for path shortening. Figure 2.4 illustrates that the distance between the metering fix and anchor point can be greater for long-side arrivals. Aircraft on these routes spend more time inside the TRACON than those on short-side arrivals. With the use of an anchor point, much of the time spent at low altitudes can be added to the cruise segment of the flight. Aircraft can also reap the benefits of path shortening, as described in the next section.

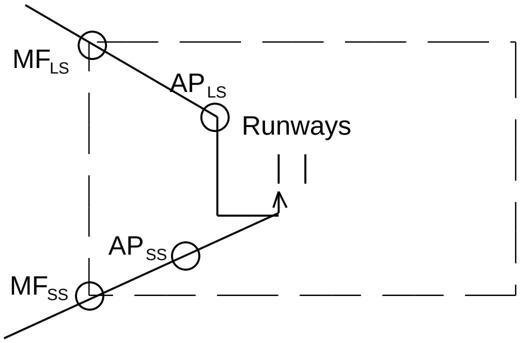

Figure 2.4 Long-side (LS) arrivals have greater potential for path shortening than short-side (SS) arrivals.

2.3 Direct Routing

A typical arrival path into a TRACON includes interception of a standard terminal arrival (STAR) route, which aircraft follow to the metering fix. As with the anchor point concept, the length of the path to the metering fix can be reduced by "cutting the corner" and flying directly to the metering fix, as shown in Figure 2.5.

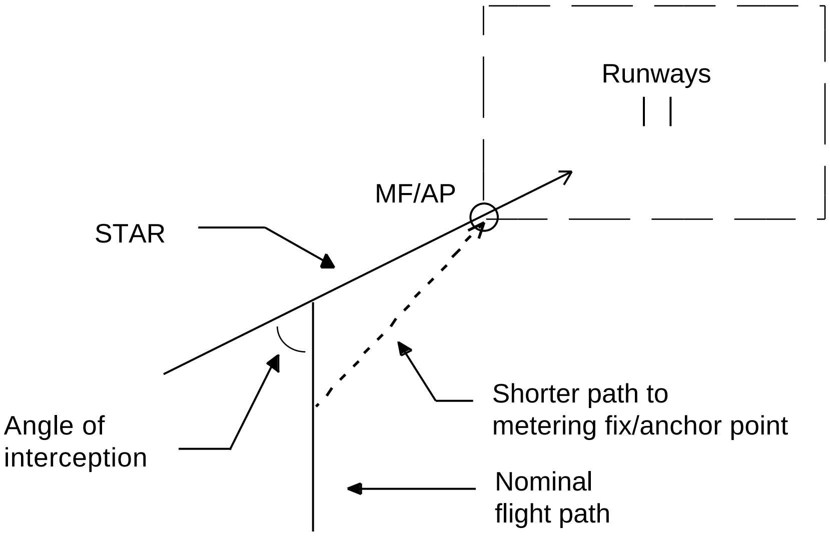

Figure 2.5 Potential benefits of direct routing are related to the shorter path length traveled.

The potential benefits of direct routing will vary depending upon the angle at which the nominal flight path intercepts the STAR as well as the distance from the metering fix (or anchor point) that the interception occurs. The benefits will also vary with the point upstream of the metering fix/anchor point at which the aircraft diverges from the nominal flight path to fly directly to the metering fix/anchor point. As with the anchor point concept, fuel savings will result if the time saved by the shorter route is absorbed with a slower cruise speed to achieve a metering fix crossing time. Also, the benefits of a shorter flight are available if time of arrival is not constrained.

3 Analysis

The optimization mechanisms proposed in this study were evaluated with aircraft performance simulations that model aircraft trajectories and fuel burn. The results of these simulations were fuel consumption data for each case considered. These data were compared to baseline cases.

For this rough-order-of-magnitude investigation, two aircraft models were selected to represent the fleet. A B737-300 (B73S) aircraft model represents large aircraft, while a DC10 aircraft model represents heavy aircraft. Comparisons were made between trajectories with the same initial and final conditions and fixed flight time. Wind effects were not considered in this investigation.

3.1 TOD Optimization

For this investigation, aircraft simulations were used to determine fuel consumption for a series of descent trajectories. A set of descent trajectories with different flight path angles was compared to the baseline case of an idle-thrust descent. The results are taken from Sorensen and Shen [2]. Each trajectory had a range of 100 nm and was constrained to meet the same final altitude, location and airspeed. Constant Mach-Calibrated Airspeed (CAS) schedules were used in each simulation, therefore either flight path angle or thrust was fixed, but not both. Figure 3.1 shows descent profiles for the idle-thrust case and the constant flight path angle trajectories.

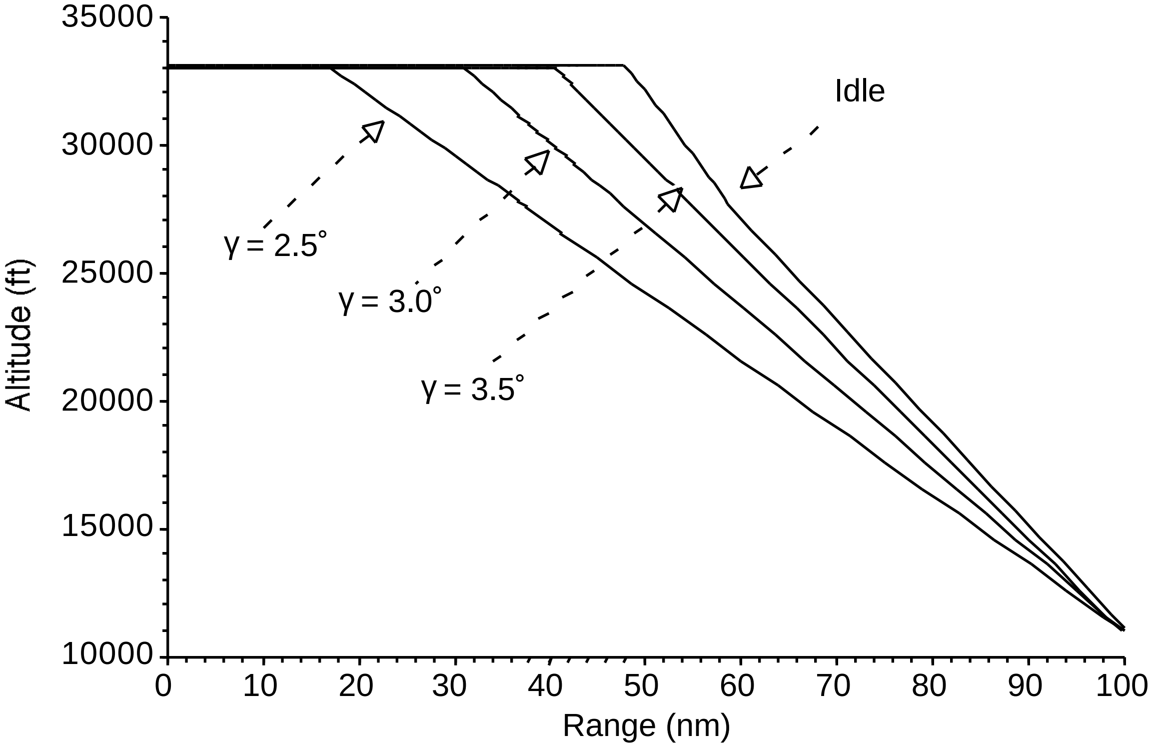

Figure 3.1 Comparison of constant flight path angle and idle-thrust descent profiles [2].

A 130,000 pound (lb) B727-200 was modeled in fast time computer simulations to descend from 33,000 ft to 11,000 ft with the speed schedules described in Table 3.1.

Table 3.1 Speed schedules used in the B727-200 descent simulations.

Constant Mach	Constant CAS (kt)
0.72	260
0.75	280
0.78	300
0.80	320
0.82	340
0.84	350

Figure 3.2 shows the amount of additional fuel consumed for each angle of descent. The idle descent case serves as the baseline.

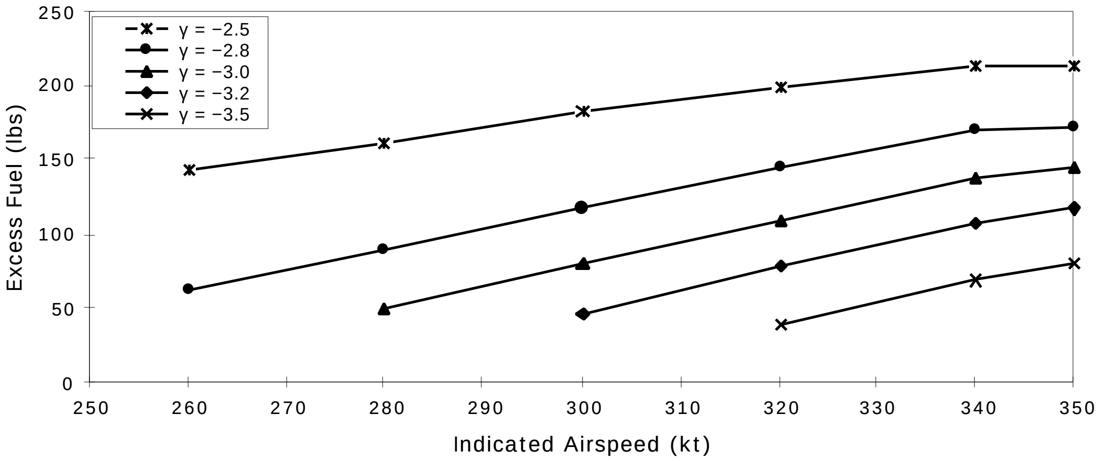

Figure 3.2 Excess fuel requirements for constant flight path angle descents compared to idle-thrust descent for the B727-200 [2].

The idle-thrust descent profile provided limited fuel savings over the case of the steepest constant flight path angle. However, fuel consumption did increase notably with the more shallow descents. The most significant example was the γ = 2.5° descent, which consumed 18% more fuel than the idle descent.

Since a B727-200 aircraft is not representative of the fleet, the results were used to approximate the descent fuel burn, referenced to the idle-thrust descent, for a 124,000 lb B73S and a 260,000 lb DC10. These conversions were performed using two methods that corroborated each other. Firstly, percentages of excess fuel burned relative to the idle-thrust descent case for the B727 were applied to the idle-thrust descent fuel burn results for the B73S and DC10. Secondly, a fuel burn ratio between the B73S (and DC10) and the B727 was used to estimate the excess fuel burned for the B73S (and DC10). The results from each method confirmed the results of the other. Points of constant time to fly (TTF) were extrapolated from these data. Figures 3.3 and 3.4 illustrate the results.

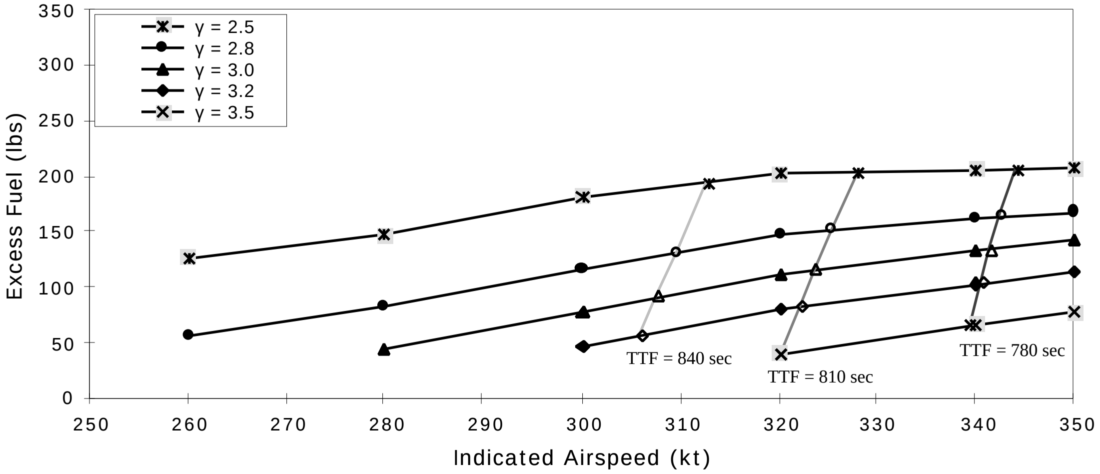

Figure 3.3 Approximate excess fuel requirements for constant flight path angle descents compared to idle-thrust descent for the B73S aircraft.

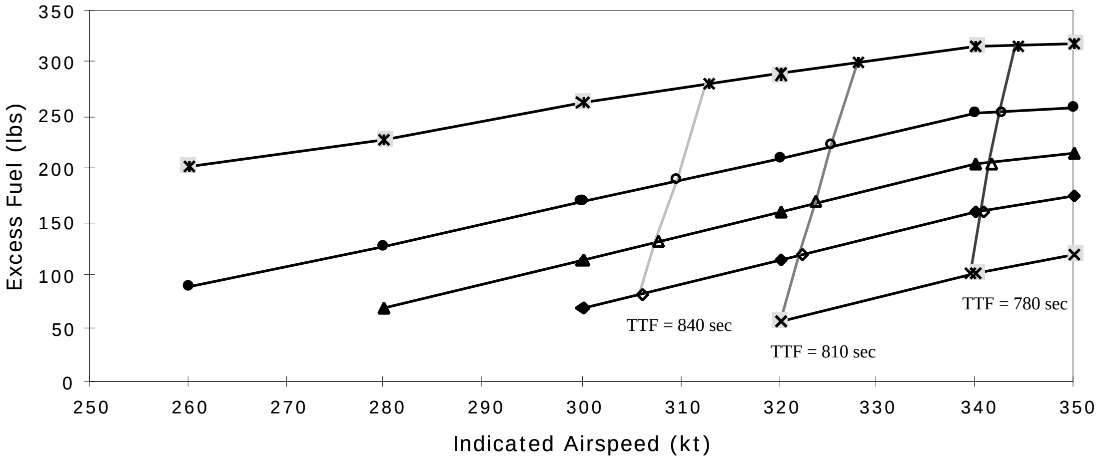

Figure 3.4 Approximate excess fuel requirements for constant flight path angle descents compared to idle-thrust descent for the DC10 aircraft.

The amount of excess fuel required during the descent was also dependent upon the aircraft weight at the TOD. Simulations were performed with a constant Mach of 0.80 and constant CAS of 320 kt. Figure 3.5 shows that heavier aircraft are more fuel efficient for a given flight path angle. These results indicate that lighter aircraft benefit more from improved TOD than heavy aircraft.

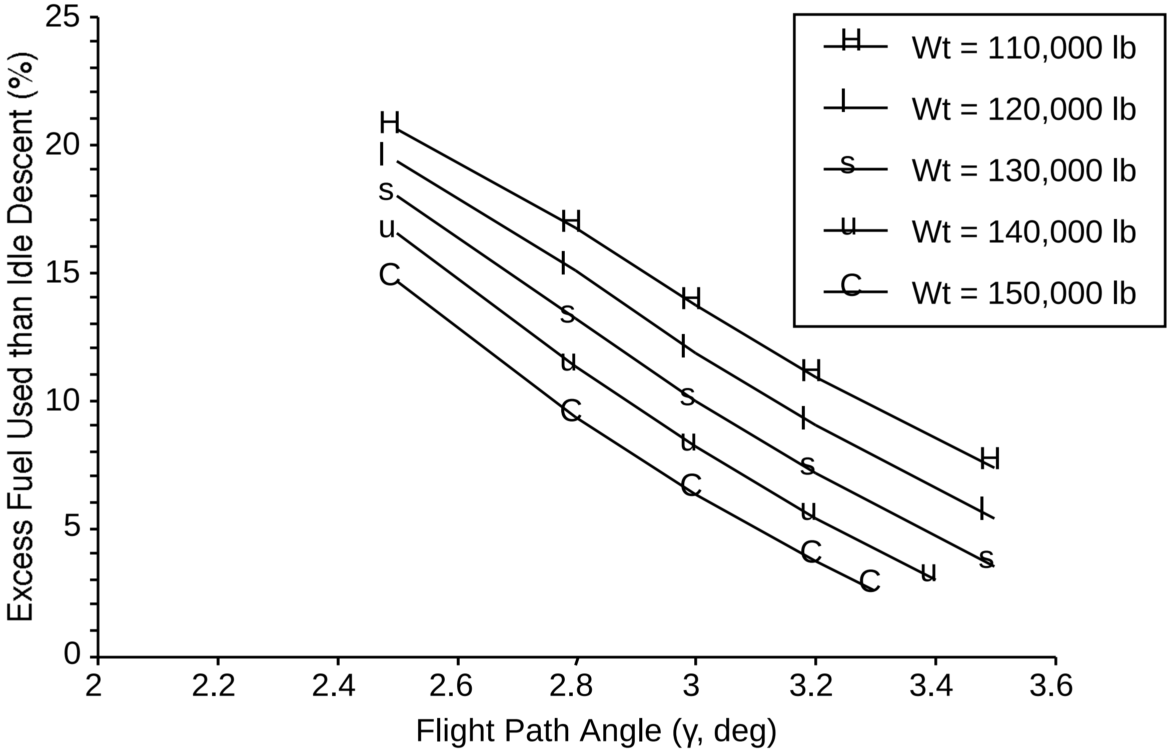

Figure 3.5 Sensitivity of excess fuel used for constant-γ descents as function of aircraft weight for the B727-200 aircraft [2].

3.2 Anchor Points

The first potential benefit of anchor points, reduced flight time at low altitude, was investigated for DC10 and B73S aircraft. A range of anchor point locations was selected downstream of the metering fix. Each aircraft was simulated from cruise, at 34,000 ft altitude, to the anchor point, at 10,000 ft altitude. A range of cruise Mach values was used, but the Mach-CAS descent schedule was fixed for all simulations. The baseline trajectory and time to fly were selected to be where the anchor point is coincident with the metering fix. In subsequent simulations the anchor point was placed further downstream, closer to the runway threshold. Speed control was used to ensure that flight time was not changed. Figure 3.6 shows the potential fuel savings for the B73S aircraft.

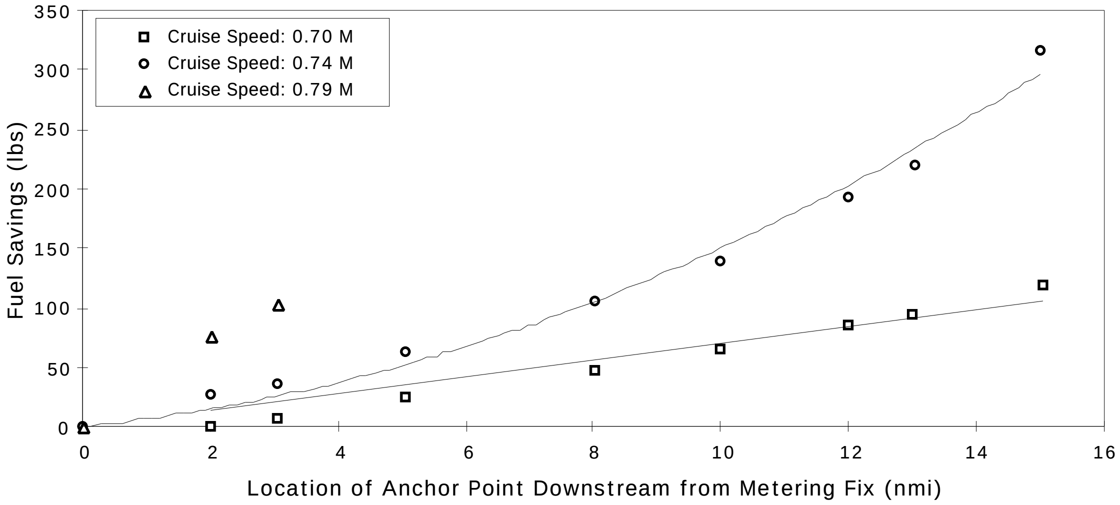

Figure 3.6 Fuel savings vs. anchor point location for a B73S with a Mach = 0.74 / CAS = 280 kt descent schedule.

Figure 3.6 illustrates the effect of the drag polar on fuel consumption. The fuel savings increases nearly linearly with anchor point location at the lower cruise speed where the drag polar is typically linear. Differences in fuel consumption become more parabolic at higher speeds. Also, note that in order to maintain a fixed flight time, the aircraft cruises more slowly, and hence, more efficiently, as the anchor point is moved downstream. Only three data points were obtained in the Mach 0.79 case due to airframe airspeed constraints.

Figure 3.7 shows that similar results were obtained with simulations of a DC10 aircraft. The fuel savings curves are more linear for this aircraft because the drag polar is shifted to the right compared to that of the B73S aircraft. The nonlinearity is therefore shifted to higher speeds. The speeds used in this simulation are in the more linear region of the drag polar.

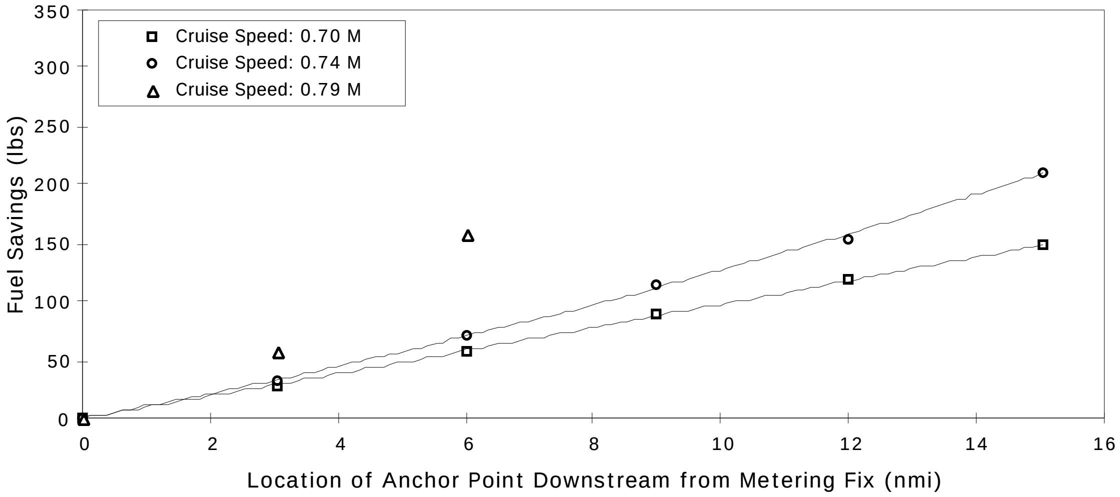

Figure 3.7 Fuel savings vs. anchor point location for a DC10 with a Mach = 0.74 / CAS = 280 kt descent schedule.

The second benefit of the anchor point concept was fuel savings due to shortened flight path. This benefit was investigated as part of the direct routing experiment since the procedures were the same.

3.3 Direct Routing

Direct routing allows an aircraft to fly directly to a metering fix (or, equivalently, an anchor point) without requiring it to follow a predetermined arrival route, i.e., a STAR. Aircraft may nominally intercept a STAR at various distances from the metering fix/anchor point and at different intercept angles, then fly along the STAR to the metering fix. Simulations were performed using three different interception locations, 70, 150 and 300 nm from the metering fix/anchor point, with two different angles of interception, 30° and 60°. The aircraft were then simulated to divert from the nominal path at various starting points upstream from the STAR, then fly directly to the metering fix.

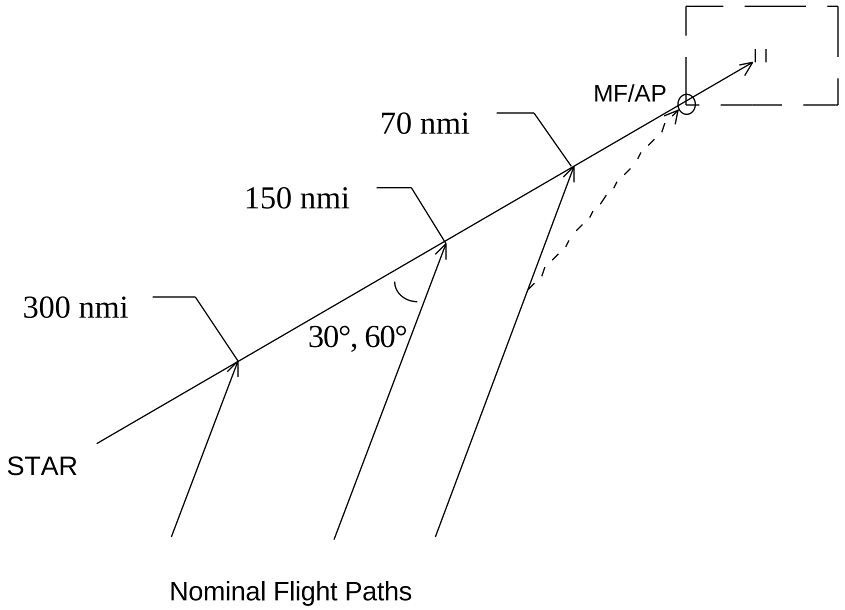

Figure 3.8 Nominal flight paths intercepting a STAR at various distances upstream from the metering fix/anchor point.

The time of arrival at the metering fix/anchor point was fixed as was the descent Mach-CAS schedule. The results are displayed in Figures 3.9, 3.10, and 3.11.

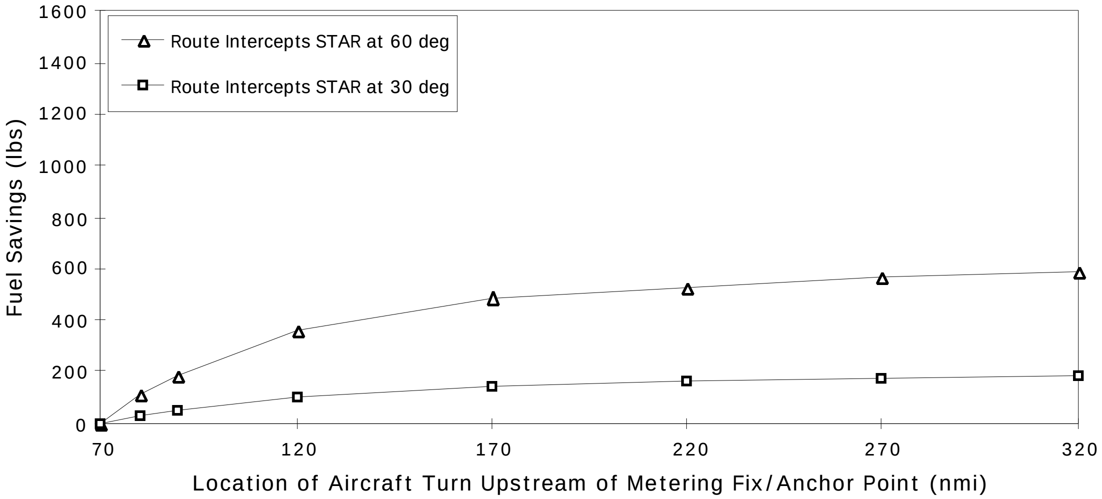

Figure 3.9 Direct Routing of a DC10. Baseline STAR Interception: 70 nm from metering fix.

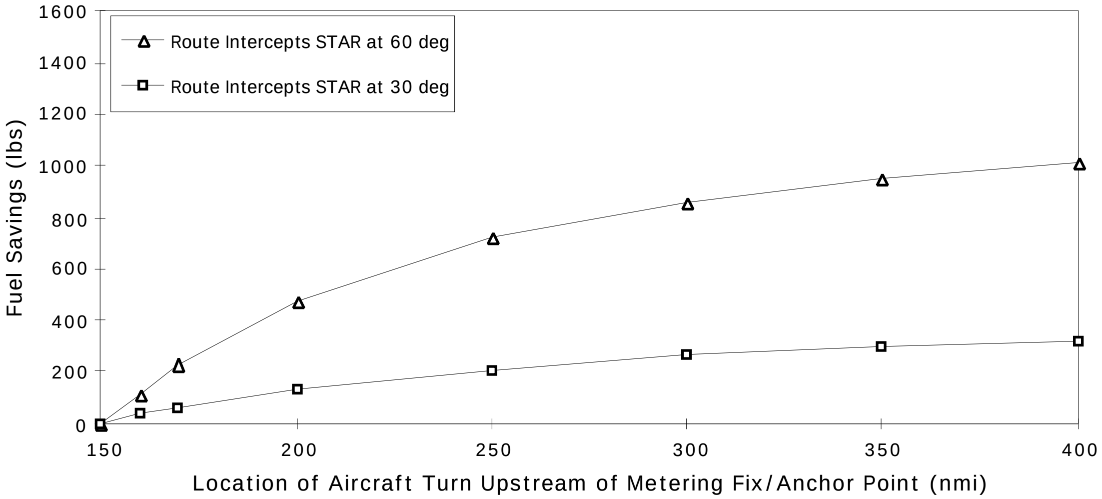

Figure 3.10 Direct Routing of a DC10. Baseline STAR Interception: 150 nm from metering fix.

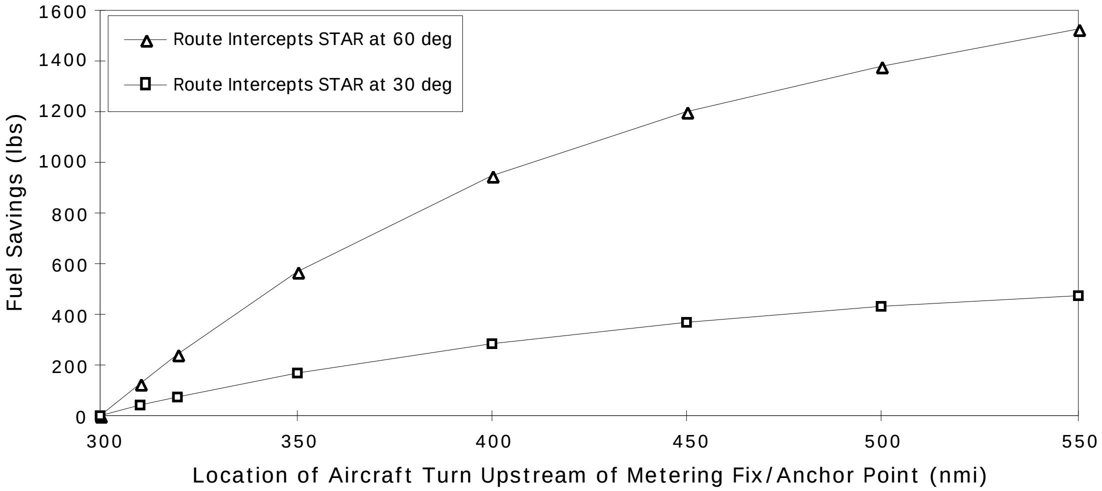

Figure 3.11 Direct Routing of a DC10. Baseline STAR Interception: 300 nm from metering fix.

The greatest benefit was achieved by cutting the corners early in the flight plan. Figure 3.9 shows nearly 12% fuel savings over the nominal flight path when the diversion from the nominal path occurred 300 nm before reaching the metering fix. Even a late decision to fly a direct route could result in fuel savings, as shown by the first few data points in Figures 3.9, 3.10 and 3.11. Approximately twice the benefit is realized for aircraft intercepting the STAR at the larger 60° angle than at 30°. A greater potential for a shortened path exists when the nominal path intercepts the STAR at a larger angle.

4 Conclusions

An estimate of fuel savings per flight was calculated for arrival trajectories into the Dallas-Fort Worth (DFW) airport, which was selected to represent a major airport. Fuel cost was estimated to be $.10/lb and weighted fuel burn averages based on typical DFW fleet mixes were used to determine fuel savings per carrier arrival. The results were then extrapolated to the national level by assuming that the sector tool benefits are applicable to carrier[4] and air taxi[5] operations at each of 67 focus airports spanning the contiguous United States. These results are presented in the Appendix.

In this preliminary investigation, fuel burn was not determined for air taxi, general aviation, or military type aircraft. Hence, an accurate bound for the potential savings for these types of operations could not be determined. However, with engineering judgment, it is estimated that each air taxi operations can potentially reap 25% of the maximum benefit of the sector tools that is achieved by carrier operations. Therefore, 25% of the maximum fuel savings per carrier operation was assumed for each air taxi operation. Based on the number of air taxi operations at each of the focus airports, this result was extrapolated to the national level.

Table 4.1 summarizes the range in fuel savings benefits achieved with each of the sector tool benefits mechanisms analyzed in this report. The broad ranges indicate that the benefit will depend on actual trajectory geometries and traffic patterns. The fuel savings per arrival was then used to determine the maximum annual dollar savings for the DFW airport.

Table 4.1 Estimated fuel savings and maximum dollar benefits at DFW for each sector tool method.

	Fuel Savings Per Flight (lb)	1997 Maximum Annual Savings ($ Millions)
TOD Optimization	0 - 223	8.3
Anchor Point	0 - 138	2.6
Direct Routing	0 - 1018	37.7
DFW Total	0 - 1379	**48.6**

If only 25%[6] of carrier and air taxi arrivals are able to realize the savings from the three mechanisms listed, the annual savings would exceed $12 million (1997 dollars) at DFW alone. For purposes of comparison, this savings would exceed the time-based benefit that was estimated to be provided by CTAS in a recent study [6].

Table 4.2 summarizes the maximum potential national savings for each sector tool mechanism. This upper bound assumes that both carrier and air taxi operations achieve benefits from the sector tool, as discussed above. A complete table of the savings at each of the focus airports is presented in the Appendix.

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[4] Air carrier operations include originating, stopover, and transfer passengers of U.S. scheduled and nonscheduled commercial air carriers submitted to Research and Special Programs Administration (RSPA). [5]

[5] In this investigation air taxi refers to commuter/regional/air taxi operations which include aircraft arrivals and departures performed by commuter/regional carriers or air taxi operations certified in accordance with FAR Part 135 or Part 121 who fly aircraft with 60 seats or less. [5]

[6] This value, although the same, is not related to the value of 25% used to estimate the maximum potential benefits of air taxi operations.

Table 4.2 Estimated fuel savings and maximum national dollar benefits for each sector tool method.

	Fuel Savings Per Flight (lb)	1997 Maximum Annual Savings ($ Millions)
TOD Optimization	0 - 223	150.9
Anchor Point	0 - 138	46.7
Direct Routing	0 - 1018	689.1
National Total	0 - 1379	**886.7**

4.1 TOD Optimization

In the TOD optimization case, a maximum fuel savings of 223 lb per flight was estimated by comparing a relatively gradual descent profile (γ = 2.5°) with the idle-thrust descent case (γ 3.5°). If the sector tool can provide this benefit for all arrivals, the 223 lb fuel savings per flight escalates to $8.3 million saved per year at DFW. If the average characteristic flight path angle of arrivals is steeper than 2.5°, then the potential cost savings is diminished as illustrated in Figure 4.1.

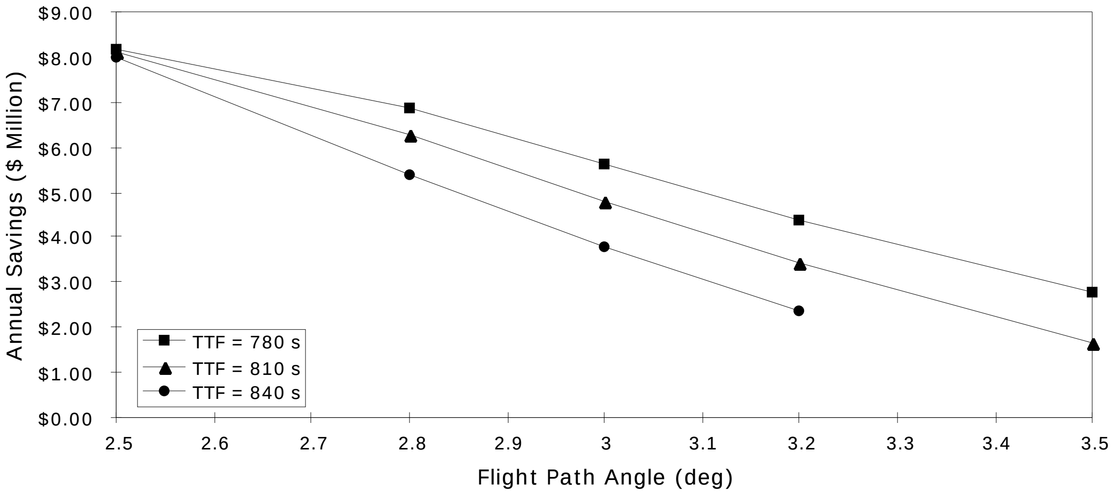

Figure 4.1 Maximum potential savings for the TOD optimization mechanism.

4.2 Anchor Points

In the anchor point case, fuel savings are achieved by moving the bottom of descent from the metering fix location further downstream to a point within the TRACON and closer to the runway threshold. The maximum fuel savings was estimated by assuming that the anchor point is located 10 nm downstream of the metering fix for long-side arrivals. No savings were assumed for short-side arrivals. If a B73S aircraft is representative of large aircraft and a DC10 aircraft is used to represent heavy aircraft, the potential fuel savings corresponds to about $2.6 million saved per year at DFW. This value was calculated assuming that one-half of arrivals are long-side arrivals.

This savings is likely to be available to all long-side arrivals since TRACON geometry permits it. Additional savings may be available if the anchor point can be moved further downstream. Figure 4.2 illustrates the range of potential savings.

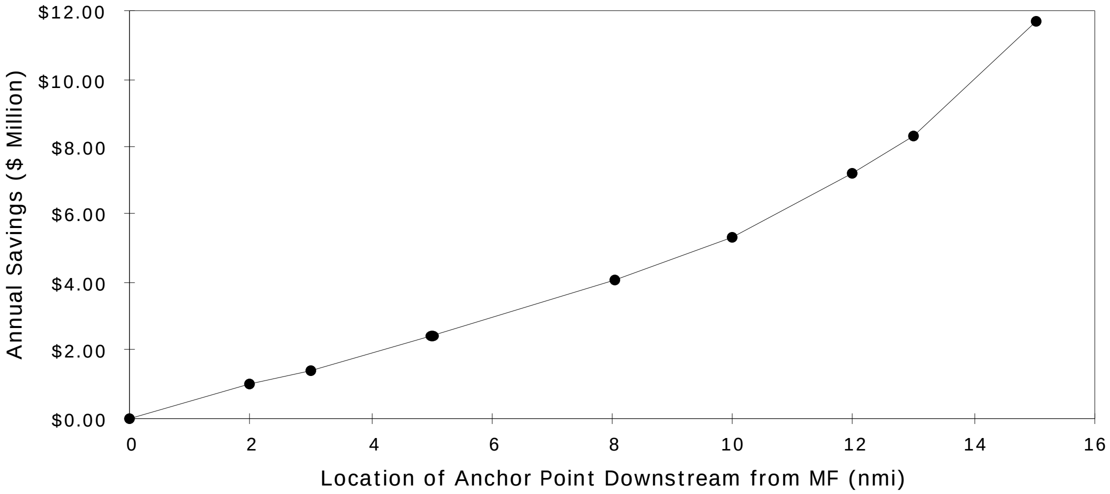

Figure 4.2 Maximum potential savings for the anchor point mechanism.

Depending on aircraft type, TRACON geometry, and the distance from the metering fix to the runway threshold, short-side arrivals may also benefit from the use of anchor points.

This investigation focused on optimizing the descent by maximizing the aircraft cruise segment. A second, horizontal, benefit is also available where, similarly to direct routing, an aircraft is routed directly to an anchor point without passing through a metering fix. The anchor point results presented here do not reflect additional savings due to this horizontal benefit.

4.3 Direct Routing

The direct routing benefits are significantly greater than the other methods because of the potential for path shortening. The greatest potential savings were observed for aircraft intercepting the STAR at the larger 60° intercept angle. If aircraft begin their direct routes as far upstream as 570 nm from their destination metering fix/anchor point, they can conserve more than 1000 lb of fuel. This escalates to $37.7 million annually at an airport such as DFW, assuming all arrivals can realize this savings. Direct routes beginning later in the flight have smaller benefits. Figure 4.3 shows the range of the maximum benefits of direct routing.

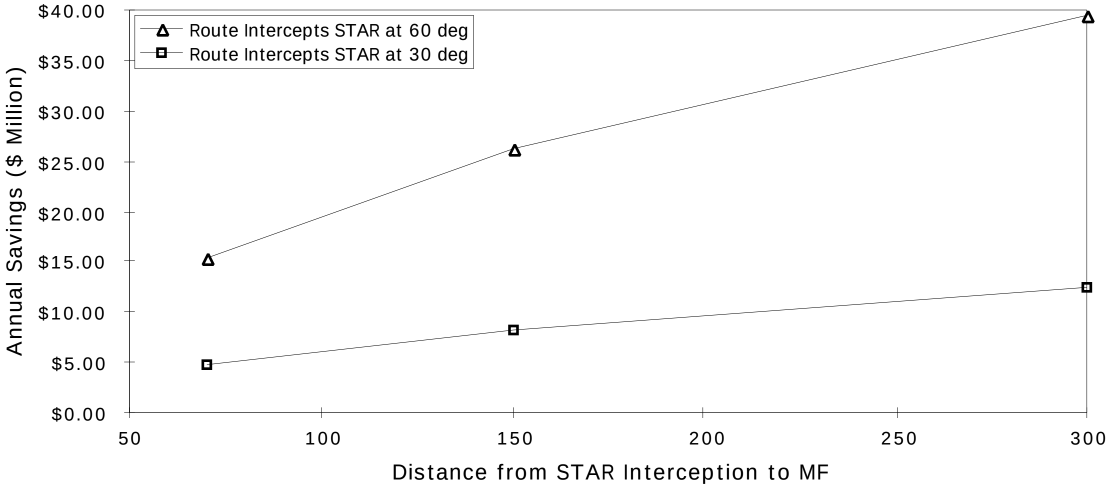

Figure 4.3 Maximum potential savings for the direct routing mechanism.

The range of direct route starting points investigated here describes the sensitivity of potential savings to various flight path geometries. The maximum benefit observed corresponded to a direct routing starting about 570 miles upstream of the metering fix. The available potential benefit will be greater for direct routes that start further upstream. The maximum available benefit should correspond to a direct route beginning at the departure airport, i.e. en route benefits.

4.4 Expected Benefit

Based on range of benefit of the various sector tool mechanisms, the expected benefit of each mechanism was estimated. Since sufficient analysis has not been performed for air taxi, general aviation or military type aircraft, no benefit was assumed for these operations. Only carrier operations were assumed to benefit from the sector tool. The sector tool benefits estimates listed are gross estimates based on engineering judgment. They represent estimates of how external factors will reduce the maximum potential benefits. These are only rough estimates, and they will change with further investigation.

The maximum and expected benefits at DFW are summarized in Table 4.3.

Table 4.3 Maximum and estimated savings for each sector tool benefit mechanism.

Benefit Mechanism	Estimated DFW Annual Savings (1997 $ Millions)			
		Maximum		Expected
	Simulation Condition	Per Flight (lb)	DFW Annual ($ Millions)	ROM Estimate ($ Millions)
TOD Optimization	2.5°	0 - 223	8.3	1.9
Anchor Point	10 nm	0 - 138	2.6	2.4
Direct Routing	60°	0 - 1018	37.7	1.7
DFW Total		0 - 1379	48.6	**6.0**

Table 4.4 summarizes the nationwide extrapolation of the maximum and expected benefits of the sector tool.

Table 4.4 Nationwide maximum and expected potential savings.

Benefit Mechanism	**Estimated National Annual Savings (1997 $ Millions)**			
	Maximum			**Expected**
	Simulation Condition	**Per Flight (lb)**	**Maximum ($ Millions)**	**ROM Estimate ($ Millions)**
TOD Optimization	2.5°	0 - 223	150.9	33.7
Anchor Point	10 nm	0 - 138	46.7	41.7
Direct Routing	60°	0 - 1018	689.1	30.8
National Total		0 - 1379	886.7	**106.2**

Table 4.5 compares the sector tool benefits with those of other candidate automation tools. At this point, this table provides little more than a straw-man comparison. The URET and UPR benefits estimates are to be determined (TBD). Thus, this table provides the framework for the future benefits analysis work that is required in order for meaningful comparisons to be made.

Table 4.5 Savings comparison between the sector tool and other benefit mechanisms.

Benefit Mechanism	**Estimated DFW Annual Savings (1997 $ Millions)**	
CTAS	**Savings Per Item**	**Cumulative Savings**
PFAST	2.6	2.6
TMA	2.2	4.3
TMA/DA[7]	4.1	6.2
Sector Tool		
TOD Optimization	1.9	1.9
Anchor Point	2.4	4.3
Direct Routing	1.7	6.0
Free Flight	TBD	TBD
URET	TBD	TBD

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[7] Previously determined capacity benefits of the Descent Advisor are accounted for here. [6]

5 Recommendations

This study has determined the potential range of benefits available using the sector tool. The range of benefits is relatively large, especially for the direct routing mechanism. This wide range of potential benefits needs to be narrowed in order to make intelligent and meaningful implementation decisions. The key questions that need to be answered are: (i) to what degree are these mechanisms in use in today's system (i.e. determine a baseline), and (ii) when these mechanisms are not in use, to what degree could they be used given the appropriate tool such as the sector tool? When these issues are quantified, we can then determine the economic benefits of the sector tool more precisely.

5.1 Detailed Analysis

This report presents the results of a preliminary investigation of the potential benefits of the sector tool. A more detailed analysis can provide more precise and accurate estimates of the benefits of the tool. Several areas have been identified as potential areas of future detailed analyses. These include

- development of aircraft models to more accurately represent current fleet mixes,
- development of new simulation parameters to comparably represent various aircraft within their performance envelopes,
- evaluation of time savings benefits of the sector tool,
- investigation of additional horizontal anchor point benefits.

5.2 Applicability

Further investigation into the benefits of the sector tool with respect to arrival and descent trajectories involves determining the applicability of the benefits mechanisms proposed in this report. Actual vertical profiles must be examined and compared to those proposed here. This includes comparison of step descents with constant-flight path angle descents. Significant discrepancies may indicate greater potential for fuel savings when using the sector tool. If actual trajectories are similar to the optimal trajectories in this report, the sector tool may not provide much benefit. Several techniques for obtaining this information should be considered.

One technique is to examine radar data such as data from Traffic Management Advisor field tests. Such data are limited to activity within the range of the radar.

A second technique for determining the applicability of the sector tool is to study aircraft traffic geometries. Examination of actual long- and short-side arrivals should reveal the utility of anchor points. Direct routing benefits can also be determined by studying the frequency of long-side arrivals and other dog-legs. Current charts and publications can provide information about arrival routes, but additional research must be performed to determine actual traffic trends.

Another area to consider in further research is the effect of rush profiles on the applicability of the sector tool optimization mechanisms. Delays in the system must be compared to the savings incurred by the sector tool to determine if the sector tool is useful during rushes. For example, direct routing may have the advantage of reduced path length and fuel consumption, but the aircraft may not have the same speed control margin to absorb additional delays. The aircraft may then be vectored, increasing path length and fuel consumption for the flight. If delays due to rushes minimize the benefit of the sector tool, perhaps less busy airports may benefit more from the tool.

Finally, potential benefits of the sector tool have only been consider for arriving aircraft. About twice as many aircraft could benefit from the tool if it can be used to optimize departures as well. Further investigation is necessary to determine the benefits, if any, of the sector tool on departing aircraft.

6 References

1. Vivona, R.A., Ballin, M.G., Green, S.M., Bach, R.E., and McNally, B.D., “A System Concept for Facilitating User Preferences in En Route Airspace,” NASA TM 4763, November 1996.

2. Sorensen, J.A., and Shen, M., “Study of Alternate Fuel Burn Models for ATC Automation,” TM 93120-02, Seagull Technology, Inc., Sunnyvale, CA, January 1993.

3. Erzberger, H., McLean, J.D., and Barman, J.F., “Fixed-Range Optimum Trajectories for Short Haul Aircraft,” NASA TN D-8115, December 1975.

4. Hunter, G., “Analysis of Descent Trajectories in the Denver Center”, TM 92120-04, Seagull Technology, Inc., Sunnyvale, CA, November 1992.

5. FAA Statistics and Forecast Branch, “Terminal Area Forecasts-Fiscal Years 1993-2010”, Department of Transportation, Washington, DC, September 1994.

6. Hunter, G., Weidner, T., Couluris, G., Sorensen, J., Bortins, R., “CTAS Error Sensitivity, Fuel Efficiency, and Throughput Benefits Analysis”, TM 96150-02, Seagull Technology, Inc., Cupertino, CA, July 1996.

7 Appendix

The following tables summarize the calculations performed in determining the nationwide saving of the sector tool. These calculations were described in section 4, Conclusions.