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COMPARATIVE ANALYSIS OF OPERATIONAL FORECASTS VS ACTUAL WEATHER CONDITIONS IN AIRLINE FLIGHT PLANNING

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16. Abstract

A study was conducted on the impact of more timely and accurate weather data on airline flight planning with the emphasis on fuel savings. This volume of the report discusses the results of Task I of the four major tasks included in the study. Task I compared flight plans based on forecasts with plans based on the verifying analyses from 33 days during the summer and fall of 1979. The comparisons showed that: (1) potential fuel savings conservatively estimated to be between 1.2 and 2.5 percent could result from using more timely and accurate weather data in flight planning and route selection; (2) the Suitland forecast generally underestimates wind speeds; (3) the track selection methodology of many airlines operating on the North Atlantic may not be optimum resulting in their selecting other than the optimum North Atlantic Organized Track about 50 percent of the time.

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1. INTRODUCTION

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PRC Speas, assisted by David R. Bornemann Associates, Inc., has conducted analyses of flight plan data for the National Aeronautics and Space Administration-Lewis Research Center under Contract #NAS3-22748.

The objective of these analyses was to assess the potential improvement in fuel savings which may be possible from improved meteorological data. Flight plans calculated from prescribed input parameters and meteorological data sets were used as quantitative indicators of differences in fuel burn and other relevant parameters. Flight plan data were provided through the cooperation of two airlines which will be referred to as "BLUE Airline" and "RED Airline" throughout this report in order to maintain anonymity.

The work program under this contract was divided into four tasks. This volume of the final report presents the findings of Task I which involved various comparisons of flight plans which were calculated on operational National Weather Service forecasts with similar flight plans based upon the verifying analyses.

None of the analyses in Task I used flight plans that were calculated in real time for actual flights. All of the plans were recreated, after the fact, on either the BLUE Airlines or RED Airlines computer flight planning systems. NASA recreated, or simulated, actual flights by submitting sets of meteorological data and flight plan inputs to BLUE and RED based on both computer-generated and actual flights. The flight plan inputs included standard values for such parameters as payload, cruise speed, aircraft type, and altitude profile so that, to the extent possible, the effect of these variables was eliminated and differences between flight plans could be attributed to differences in the meteorological data.

The major findings and conclusions under Task I are presented in the next section. This is followed by sections on the analysis methodology and the extent and validity of the data. Subsequent sections fully describe Task I and present the findings in detail.

2. SUMMARY AND KEY FINDINGS

****

Task I compared fuel burn, flight time, air miles and ground miles on flight plans that were based on the U.S. National Weather Service (NWS) forecasts with corresponding plans based on the NWS verifying analysis to determine the fuel savings that were possible through improved weather forecasts. The comparisons involved flight plans that were produced on the RED and BLUE Airlines flight planning systems. Key findings were:

- Comparisons between B747 flight plans on operational routes (which were probably not minimum fuel tracks) based on the NWS forecast and plans on the same routes based on the verifying analysis showed that fuel savings per flight for B747 aircraft would average 462 kg (151 gal.) if the forecasts and verifying analyses were identical. Different savings of comparable order of magnitude would result in other regions of the world.

- If, in addition to the improved forecasts, operational constraints imposed by the NAT track system on the use of minimum time tracks and optimum flight levels were removed the average potential savings per flight increases to 1394 kg (458 gal.).

- Airlines whose track selection methodology is based on minimum time rather than minimum fuel, and airlines that select a preliminary minimum time track at a constant flight level before optimizing the flight level, do not select the optimum fuel NAT track 45 to 50 percent of the time.

- Comparisons of track selections between Amsterdam and Caracas on a single fixed route that had been used by one airline, and on eight other routes laid out by NASA, showed that the original route was optimum only six times out of 60 cases. The average fuel burn penalty for being on this route was 1054 kg (347 gal.) per flight.

In Task I, NASA provided PRC Speas with approximately 20,000 flight plans that had been computed on either the BLUE or RED flight planning systems using weather data for various days in 1979. These plans consisted of five categories:

- Flight plans on minimum time/minimum fuel tracks at optimum flight levels between various North Atlantic and North Pacific city-pairs;
- Flight plans on "AIDS recreated routes" which are operational routes that were actually flown on that day by aircraft equipped with an Aircraft Integrated Data System (AIDS) that collects wind and temperature data on board and stores them on magnetic tape for subsequent processing on the ground;
- Plans on minimum time tracks at five fixed flight levels on various North Atlantic routes;
- Plans between Amsterdam and New York on tracks in the North Atlantic Organized Track System;
- Plans on nine fixed routes between Amsterdam and Caracas.

Computer programs were developed to analyze these data and produce statistics on the differences in fuel burn, flight time, air miles and ground miles between various groups of plans such as AIDS flights vs. the corresponding minimum time track, or the minimum time track on the forecast weather vs. the minimum time track on the actual. In every case, the flight plans used the National Weather Service (NWS) operational forecast and verifying analysis. The plans based on the verifying analysis represent the actual weather as depicted by the NWS on the analysis valid at that time and are not necessarily representative of the actual weather encountered by that flight.

Several features inherent in the BLUE system, the NWS analysis model, and NASA's input procedures caused some anomalies in the data base. Three of these were somewhat significant.

First, an error checking procedure on the valid times of observations in the NWS software caused pilot reports and AIDS data submitted by NASA to be ignored, and resulted in the verifying weather analyses being always identical to the forecasts in equatorial regions and the Southern Hemisphere. As a result data from some flights in these regions had to be discarded.

Second, AIDS recreated flights in the BLUE system used direct, great circle routes between the origin and the oceanic entry point while the minimum time track plans were restricted to airways. This resulted in a distance bias generally favoring the AIDS flights which sometimes gave a fictitious indication of fuel savings when AIDS flights were compared to minimum time tracks.

Third, since NASA's inputs to the BLUE system tried as closely as possible to recreate the original conditions under which AIDS flights operated, flight levels were restricted to those used by the AIDS flight while minimum time track plans were calculated at optimum levels. This resulted in fuel burn differences which were attributed to the flight level difference rather than weather data differences.

Adjustments based on manual analysis were made to the computer output to correct the findings for these anomalous data. The adjustment factors were developed from a detailed analysis of actual flight level and distance differences in the BLUE flight plans.

Five comparisons were conducted between different flight plan groups, a sixth case considered track selection procedures on the North Atlantic, and a seventh case considered the penalty associated with the use of a fixed route between Europe and the Caribbean. A summary of the findings from each of these cases is presented below.

Case 1 - The first case compared AIDS flights planned on the forecast weather to AIDS flights planned on the verifying analysis. Since all other flight plan parameters (route, flight level, etc.) were held constant, differences between the flight plans reflected differences between the weather data sets and, in this case, the potential fuel savings that would result if the forecast were improved to the point at which it was equal to the verifying analysis.

The number of flight plan comparisons in the sample and the average differences (forecast plan value minus analysis plan value) in fuel burn were:

BLUE System Flight Plans	Sample Size	Burn Difference
All eastbound flights	222	369 kg
North Atlantic eastbound flights	109	569 kg
All westbound flights	305	-140 kg
North Atlantic westbound flights	143	-295 kg

RED System Flight Plans	Sample Size	Burn Difference
All eastbound flights	95	384 kg
All westbound flights	147	-371 kg

The positive differences eastbound, and negative differences westbound indicated that wind speeds are generally underestimated in the NWS forecast model.

Case 2 - Case 2 compared minimum time tracks based on the forecast to minimum time tracks based on the verifying analysis and, as such, was quite similar to Case 1 except for the use of different routes. The objective was to determine the potential fuel savings that would result if the forecast were equal to the verifying analysis and if carriers could use random tracks.

The number of comparisons in the sample and the average differences in fuel burn in this case were:

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BLUE System Flight Plans	Sample Size	Burn Difference
All eastbound	229	739 kg
North Atlantic eastbound	199	815 kg
All westbound	231	-409 kg
North Atlantic westbound	202	-322 kg

RED System Flight Plans	Sample Size	Burn Difference
All eastbound	29	475 kg
All westbound	29	-324 kg

Case 3 - Case 3 compared AIDS recreated flights on the forecast weather to the corresponding minimum time track on the forecast weather. The objective was to show the potential fuel savings that could result if carriers were free to fly the minimum time track.

Based on the raw data the sample sizes and the average differences or savings in fuel burn were:

BLUE System Flight Plans	Sample Size	Burn Difference
Eastbound North Atlantic	36	511 kg
Westbound North Atlantic	49	1978 kg

RED System Flight Plans	Sample Size	Burn Difference
Eastbound North Atlantic	7	1892 kg
Westbound North Atlantic	10	1760 kg

Since this case compared AIDS flights to minimum time tracks, the BLUE data were distorted due to the direct routings and flight level differences. Estimates of the effect of these routing and flight level differences were computed and the estimated BLUE differences after these adjustments were applied were:

Eastbound	1061 kg
Westbound	1397 kg

Case 4 - Case 4 was identical to Case 3 except that both the AIDS flights and minimum time tracks were based on the verifying analysis.

Fuel burn differences using the raw data were:

BLUE System Flight Plans	Sample Size	Burn Difference
Eastbound North Atlantic	35	666 kg
Westbound North Atlantic	48	2096 kg

RED System Flight Plans	Sample Size	Burn Difference
Eastbound North Atlantic	7	1931 kg
Westbound North Atlantic	10	1937 kg

After applying an adjustment for the routing and flight level differences, the BLUE savings were:

Eastbound	1216 kg
Westbound	1515 kg

Case 5 - Case 5 combined the conditions of Cases 3 and 4 and compared AIDS flights on the forecast weather to minimum time track flights on the verifying analysis. The objective was to show the combined savings from improved forecasts and from eliminating ATC restrictions on the use of the minimum time track.

Again, based on the raw data alone, the potential savings were:

BLUE System Flight Plans	Sample Size	Burn Difference
Eastbound North Atlantic	36	1311 kg
Westbound North Atlantic	49	1594 kg

RED System Flight Plans	Sample Size	Burn Difference
Eastbound North Atlantic	6	1989 kg
Westbound North Atlantic	10	1220 kg

Applying the adjustment to the BLUE data results in savings of:

Eastbound	1861 kg
Westbound	1013 kg

North Atlantic Track Selection

Analysis of flight plans run on each of the North Atlantic Organized Tracks at each available flight level on each of 30 days in both directions tested three hypotheses, each of which is followed by some airlines and is incorporated in their track selection algorithms.

1) On 40 out of 84 "days" (30 eastbound and 30 westbound for BLUE, and 16 eastbound and 8 westbound for RED) the minimum time track was not coincident with the minimum fuel track. Thus, airlines whose track selection is based on time rather than fuel are on the wrong track 45 percent of the time.

2) In 28 out of 60 cases the minimum time track selected at FL330 or FL350 was not the minimum fuel track at optimum altitude. This indicates that airlines that select a preliminary minimum time track at a constant flight level and then optimize for fuel in the flight plan are on the wrong track 47 percent of the time and incur an average fuel burn penalty of 248 kg each time they are on the wrong track.

3) In 19 out of 60 cases the minimum fuel track on the actual was not the same track as the minimum fuel track on the forecast. This is contrary to the beliefs of many carriers who feel that the weather changes so slowly that the best track does not change between the forecast and the actual even though the time and fuel burn on that track might change.

3. DISCUSSION OF DATA

****

All of the flight plans that were used in the Task I analyses were based upon weather data and operating conditions that actually existed on selected days during 1979. A global weather experiment was being conducted at that time and, as a result, significantly more observational data were available and routinely input to the U.S. National Weather Service (NWS) forecast and analysis models.

A number of Boeing B747 and McDonnell Douglas DC-10 aircraft of several international airlines were equipped with an Aircraft Integrated Data System (AIDS) during the study period. AIDS automatically collected on board the aircraft and stored on magnetic tape readings of position, altitude, temperature, wind velocity and time. These AIDS data were used directly in Task III. However, in Task I the AIDS data were only used to identify operational flight routes that were used in the comparisons. The remainder of this section of the report discusses the weather data and the flight plan data produced by the BLUE and RED flight planning systems.

3.1 WEATHER DATA

All of the weather data used in Task I were from either an operational NWS forecast (the Nine Level Primitive Equation Model used by the NWS in 1979) or from the verifying analysis valid at the time of that forecast (the Flattery Analysis Model). Although this verifying analysis is sometimes referred to as the "actual analysis" or "actual weather" throughout this report, it should be understood that it is the actual weather as represented by the Flattery analysis and is not necessarily the same as the actual weather observed by AIDS equipped aircraft on that day. These data are routinely produced by the NWS and the forecast is translated into digital form and transmitted to airlines for use in flight planning. For those days included in this study the NWS produced a copy of the 18-hour and 24-hour forecasts and the corresponding verifying analyses (as appropriate) on magnetic tape for subsequent use by NASA in recreating flight plans for that day.

The NWS forecast model that was operational at the time these data were gathered was essentially a northern hemispheric model. For latitudes below approximately 20°N and the Southern Hemisphere the present analysis was issued as a forecast. NASA submitted extensive AIDS data and pilot reports to the NWS to enhance the accuracy of the NWS analyses for this study. It was not known at that time, but the NWS analysis program in checking the valid times of the additional observations discarded all of the NASA supplied data in these southern areas. This caused the "forecast" and the verifying analysis to be identical in these southern latitudes. Thus, flight plans for flights in these regions showed no difference between the forecast and the actual.

Data normally are provided to the airlines in digital form, the so-called Aviation Digital Forecast, in a Marsden Square format and are transmitted over high speed teletype lines to airline users. Wind and temperature data are included for various levels including the 300 mb., 250 mb., 200 mb., and 150 mb. levels which were of most interest in this study. In addition, the height of the tropopause is identified. Each Marsden Square is ten degrees of longitude by ten degrees of latitude and data are included for sub-square points within each Marsden Square. The density of the sub-squares varies with latitude. At mid-latitudes the sub-square points are separated by 2-1/2 degrees latitude and five degrees longitude. Thus, data points in this critical area are about 150 to 250 nm. apart.

The density of the Marsden Square data points introduces a potential error in the flight planning process that will be addressed in the next section of this volume. Most airlines have developed their own algorithms for interpolation between sub-square points to determine the wind factor to be used for a flight plan segment. As a result the same forecast issued by the NWS to all airlines is likely to result in different segment wind forecasts by the time the forecast appears in individual flight plans.

The NWS analysis and forecast cycle repeats twice daily. The analysis times are 0000Z and 1200Z. Based upon the worldwide observation data input to the analysis at these times, forecasts of 12, 18, 24 and 30 hours are computed and offered to the airlines. For this project NASA used the 18 and 24 hour forecasts following the procedure utilized by most airlines.

3.2 FLIGHT PLAN DATA

The flight plans used in all of the Task I analyses were generated either by the BLUE or RED flight planning systems. NASA provided these airlines with copies of the appropriate Aviation Digital Forecast Data on magnetic tape along with flight plan requests that were reconstructed from the operating conditions in effect on that day, such as the North Atlantic Organized Tracks (NAT Tracks). By providing the forecast and verifying analysis data, it was possible to simulate flight plans that might have been calculated on that day even though they were actually being rerun sometime later.

Although the routes and altitudes used were those flown by actual AIDS equipped aircraft, it is important to note, as mentioned earlier, that in Task I no comparisons were made with the actual fuel burn results of these flights. All of the analyses involve simulations of flights as represented by flight plans. In most cases no flight actually operated according to this plan on that day and there is no certainty that, had such a flight operated, its actual flight time and fuel burn would have been equal to that calculated on either a flight plan based upon the forecast or on a plan based on the verifying analysis.

3.2.1 BLUE Flight Plans

Input options in the BLUE flight planning system allow for specification and control of the weather forecast data, the payload, cruise speed, fuel reserves, altitude profile and route. For the Task I analyses each of these parameters was held constant, to the extent possible, so that differences between flight plans on the forecast and flight plans on the verifying analysis could be attributed entirely to differences in the weather data. (For some of the analyses the routes were varied while the same weather data set was used.)

NASA submitted up to 760 flight plan requests to BLUE for each day on which data were collected. (A total of 30 days were included in the Task I comparisons. Two days were from January and the remainder were days from the months of August through November.) For each "flight" considered a plan was run on the 18-hour or 24-hour forecast weather and another was run on the appropriate verifying analysis for that day. Therefore, up to 380 flights were considered for each day. The actual number varied because such things as the number of NAT Tracks varied and the number of AIDS equipped flights varied.

The flight plans run on the BLUE system consisted of five categories. These were:

- <u>Minimum time tracks (MTTs)</u> at optimum flight levels between various city-pairs normally served by BLUE or the other airlines that use the BLUE flight planning system. Most of these were North Atlantic flights but one each day was for a Pacific operation between Tokyo and Seattle.

- "AIDS recreated flights" or flight plans using BLUE aircraft input parameters but on routes that were actually flown on that day by some AIDS equipped aircraft of BLUE or the other airlines that use the BLUE system. Flights in all regions of the world were included in this group.

- Minimum time tracks at five fixed flight levels between Amsterdam and New York. These plans were run in each direction at flight levels 290, 310, 330, 350 and 370 (eastbound) or 390 (westbound).

- North Atlantic organized tracks between Amsterdam and New York, and between Madrid and New York. A flight plan was run at each available flight level (except FL390) on each track, in each direction.

- Amsterdam-Caracas tracks. Flight plans were run at five levels, in both directions, on nine fixed routings between Amsterdam and Caracas, one of which was the route routinely used for actual flights between these cities.

The weather data for each day were submitted by NASA on magnetic tape and simulated a real time transmission of the Aviation Digital Forecast Data. The NASA flight plan requests then specified the forecast valid time that was to be used on that plan.

Each plan was identified by a NASA flight number to assist in identifying certain categories of flights, such as MTT flights or NAT Track flights, in the subsequent analyses but also to de-identify airlines which may have actually operated a similar flight on that day. Since BLUE provides flight plans to several other airlines and since the routings for some of the flights in this analysis were recreated from actual AIDS flights, this de-identification was deemed to be necessary.

All flight plans run on the BLUE system used either the B747 or DC-10 performance data and were flown at standard cruise which, in the BLUE system, is Mach .84 for B747s and Mach .83 for DC-10s. (In fact, except for one flight plan each day that was run on the MTT selected by the Gander, Newfoundland, Oceanic Control Center, all BLUE plans were based on B747 aircraft.)

NASA initially attempted to calculate all flight plans from a constant zero fuel weight (ZFW) of 195,000 kg and all plans at optimum flight levels were based on this ZFW. However, for some of the comparisons at fixed flight levels the B747s at this ZFW were too heavy to reach the specified level. All of the fixed level comparisons were then run from a ZFW of 165,000 kg.

Although a constant value was used for alternate fuel, reserve fuel which is partly a function of trip length varied slightly. Therefore, the landing weights for all flight plans were close but not exactly equal.

Several methods were available to specify the desired route on the BLUE flight plans. Pre-stored fixed routings could be identified by a track number, MTT routings could be requested by identifying the origin and destination, and any other route could be input by identifying the check points that comprise the route. When the MTT was requested the computer restricted the selection to operationally feasible routes. That is the route was restricted to airways in areas where airways exist and to appropriate intersections of latitude and longitude off-airways or over the ocean such as on the North Atlantic where flights are restricted to whole degrees of latitude at ten degree longitude crossings. When the route was specified in the input the flight plan was based upon a direct great circle routing between each of the input checkpoints.

3.2.1.1 Error Sources

Although keeping the input parameters of cruise, zero fuel weight, etc. constant should have minimized errors, some errors were introduced by the inherent features of the flight planning system. Time and fuel burn comparisons were distorted to some degree by inconsistencies in the weights, flight levels, or routings between the flight plans being compared. The effect and magnitude of these errors on the overall analysis are discussed below and in more detail, with the findings in Section 5.

Since the gross weight of an aircraft at any moment is a principal factor affecting fuel consumption, it is essential that the weights of two aircraft be identical if one is to use fuel consumption as an indicator of the relative efficiency of one flight plan or route over another. Since the choice of route or other flight parameters affects the length of the flight, and thus the fuel consumption and gross weight, it is not possible for two aircraft to be at the same weight throughout their flight unless they are on the same route, same flight level, same weather data, same speed and started at the same time and weight. Because of the slight variations in reserve fuel, these flight plan calculations started at different landing weights even though the payload or zero fuel weight was held constant. As the segment by segment calculations proceeded along the flight plan route the weight differences became larger as the route, wind or temperature varied.

The differences in landing weight resulting from reserve fuel differences are very small - typically from zero to 100 kg. These would not significantly affect the overall analysis. Some of the enroute differences grow to significant amounts, however, and one must consider that in some of the flight plan comparisons a portion of the fuel "savings" or "penalty" is the result of weight differences rather than improved meteorological data.

Just as weight affects fuel consumption, so does altitude. Substantial fuel savings can result from higher altitude operations. Therefore, in general if one is using flight plan fuel consumption as an indicator of the relative effectiveness of two different weather data sets the flights must be planned at the same altitudes. For some of the flight plans calculated at optimum altitude, weight differences, route differences or operational considerations inherent in the BLUE flight planning system, such as the requirement that step climbs be made only at checkpoints, resulted in plans being calculated at flight levels that differed from the levels on the plans with which they were compared.

Finally, routing differences introduced a significant error in some of the analyses. At the time the data for this project were being collected NASA believed that the most significant results in the North Atlantic area would be found in comparisons of the over ocean portions of flight plans and concentrated on identifying the over water portions of the routes. The computer's default selection was accepted for the over-land portion. As a result, MTT routings used airways routings to the ocean while plans on the NAT Tracks or those on routings recreated from AIDS flights used more direct routes from the origin to the first ocean checkpoint and from the last ocean checkpoint to the destination. On a flight from New York, for example, where the airways routing from JFK to

YYT to 48N50W is approximately 1,125 nm. the direct routing is 1,107 nm. The airways distance from Houston to Goose Bay to 56N 50W is 2,495 nm. while the direct distance is 2,460 nm.

3.2.2 RED Flight Plans

The procedures for producing flight plans on the RED system were essentially similar to those for BLUE. Input options allowed for specification of the payload, cruise speed, fuel reserves, altitude profile and route. The RED track selection system selects on the basis of minimum fuel rather than minimum time. Where "minimum time track" is mentioned in the following discussion "minimum fuel track" (MFT) is implied if the reference is to a track selected on the RED system.

NASA submitted an average of 160 flight plan requests per day covering 80 "flights" for each day on which data were collected.

RED data were collected for 29 days during the same time period as the BLUE data but not necessarily on the same days. There are a few days for which there are RED data but no BLUE data and there are days on which there are only BLUE data, but in most cases data were collected by both airlines on the same day.

Unlike BLUE, the RED flight planning system is not used by other airlines that were involved in this project. Thus, the plans included in the analyses represent a smaller number of flights and are restricted to the geographic areas in which RED normally operates. The flight plans run on the RED system corresponded to the categories of BLUE flight plans except for the Amsterdam-Caracas category which was not included in the RED analysis. The RED categories were:

- MTTs/MFTs at optimum flight levels between New York and London;

- "AIDS recreated flights" on North Atlantic and Polar routes actually flown on that day by AIDS equipped RED aircraft;

- MTTs/MFTs at fixed flight levels between New York and London, New York and Rome, New York and Paris, New York and Madrid and between Chicago and Amsterdam;

- NAT Tracks between Amsterdam and New York, at each available flight level, on each track and in both directions.

All of the RED flight plans used B747 performance data, Mach .84 cruise and were based upon a ZFW 193,000 kg. Again, as in the BLUE case, for flight plans run at specified fixed flight levels the ZFW was reduced to 163,000 kg to insure that the specified altitude could be reached.

There is a significant difference between the two flight planning systems in that the RED system always used an operationally feasible route. When a direct route was requested, for example, from the origin to the first ocean check point, the RED system would select an airways routing rather than the great circle route. Therefore, the RED flight plan comparisons were not subject to this potential error in distance between AIDS recreated plans and MTT plans. However, the RED comparisons were still subject to the less significant errors resulting from weight and flight level differences.

Although it does not affect comparisons between RED plans, there is another significant difference between the systems that affects comparisons of BLUE plans with RED plans. RED uses a distinctly different approach toward processing the weather data. Flight plans run on the BLUE system were run on either the 18-hour or 24-hour forecasts provided by NASA, whereas the RED system used both forecasts, interpolating between them according to the departure time of the flight. Similarly, each system uses a different approach for interpolating between Marsden Square data points to arrive at wind components for flight plan segments.

In addition to this difference in weather data processing, the two systems most certainly employ different algorithms for calculating aircraft performance parameters such as altitude capability and fuel consumption. As a result it is safe to say that, given the same input data, the two systems would not produce exactly the same result. This potential source of error has to be considered carefully in any comparison involving both systems.

4. ANALYSIS METHODOLOGY

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The objective of the study as set forth by NASA required that specific comparisons be made between categories or groups of flight plan types. Four categories of flight plans were provided for the study:

(1) Operational flight plans based on forecast weather;
(2) Minimum time/minimum fuel plans based on forecast weather;
(3) Flight plans based on the verifying analysis;
(4) Minimum time/minimum fuel plans based on the verifying analysis.

Comparisons were made of flight plan parameters such as fuel burn and flight time between groups 1 and 3; 2 and 4; 1 and 2; 3 and 4; and 1 and 4. The remainder of this section of the report describes briefly how the raw data were reduced and the various analyses were made.

4.1 DATA REDUCTION

Since the normal means of delivery of flight plans to flight crews is via teletype, both RED and BLUE output flight plans in a format compatible with teletype transmission. The flight plans will include addresses, message switching codes and line control characters. For this project, the flight plans were copied on magnetic tape in this "teletype image" format. Therefore, the first, and most tedious, task was to scan the tapes to extract and identify those data which were to be considered in the analysis.

Computer programs were developed which extracted data, completed most of the analyses automatically, and presented statistical results. Each day's data for each airline were contained on one tape. Therefore, a total of 59 tapes had to be reviewed to extract the data for some 30,000 flight plans.

Files were created to store pertinent data for further analyses as the tapes were scanned. Figure 4-1 lists the file entries that were saved for each flight plan and Figure 4-2 lists the file entries for each flight plan segment. Most of these data were read directly from the flight plan but several had to be derived, calculated or inferred from the available data as discussed below.

Group Code - Each flight plan was assigned a code to identify to which of the five categories (discussed in Section 3.2.1) it belonged, such as "AIDS recreated" flight, or "Amsterdam-Caracas" flight. This assignment could be determined only through knowledge of the flight numbering system. For example, all BLUE Amsterdam-Caracas flights were numbered 381 through 479, while all RED and BLUE westbound NAT Track plans were numbered 1 through 60.

Figure 4-1

DATA FILE ELEMENTS FOR FLIGHT TOTALS

- Date
- Origin Airport
- Destination Airport
- Group Code
- Airline Code (BLUE or RED)
- Flight Number
- Weather Forecast Valid Time
- Flight Time
- Takeoff Weight
- Landing Weight
- Ground Distance
- Wind Component
- Fuel Burn
- Altitudes
- Run Code
- Region
- Direction
- Nautical Air Miles
- Ratio of Air Miles to Ground Miles
- Sequence Number of File Entry

Figure 4-2

DATA FILE ELEMENTS FOR FLIGHT SEGMENTS

- Date
- Origin Airport
- Destination Airport
- Flight Number
- Airline Code
- Weather Forecast Valid Time
- Identification of From Point
- Identification of To Point
- Segment Flight Level
- Segment Flight Time
- Segment Fuel Burn
- Segment Distance
- Segment Wind Direction and Speed
- Segment Outside Air Temperature
- Run Code
- Segment Nautical Air Miles
- Region
- Ratio of Air Miles to Ground Miles
- Direction
- Sequence Number

Wind Component - While the wind component was presented directly on RED plans, on BLUE plans it had to be determined from the wind correction angle, ground speed and air speed.

Run Code - The run code was added to identify the flight plan as one based upon the forecast or one based upon the actual weather. There was no such identification printed anywhere on the flight plan and this could be determined only from the sequence of the plan on the tape. The plan on actual weather always followed immediately its corresponding plan on the forecast. (This was a potentially serious source of error since an out-of-sequence plan could distort the results. However, subsequent checks on such items as origin-destination and date during processing, and manual review of the analysis results verified that there was little likelihood that plans were assigned the wrong run code.)

Region and Direction - The region of the world and direction of flight were identified by reference to a city-pair table which was created specifically for this purpose. So, for example, KJFK-EGLL (or New York to London) was identified as an eastbound North Atlantic flight while OMDB-EDDF (Dubai-Frankfurt) was classed as a westbound Mid-East flight.

The regional categories that were included in the table, and a general description of the area or flights that were included in each region, were:

- North Atlantic - flights between Europe and eastern North America;
- Mid-Atlantic - flights between Europe and the Caribbean or South America, or flights between the eastern U.S. and Africa;
- Pacific - flights between Japan and Anchorage or the U.S., and those between Honolulu and California;
- Africa - flights within Africa or between Europe and Africa;
- Caribbean - flights within the Caribbean, Central America or South America;
- Polar - flights between Anchorage or the U.S. West Coast and Europe;
- Far East - flights within the area bounded by Japan, Australia and Southeast Asia;
- Europe - flights within Europe;
- United States - flights within the U.S.;
- Mid-East - any flights traversing the Mid-East to or from Europe such as Frankfurt-Dubai or Frankfurt-Bangkok.

4.2 COMPARISONS BY FLIGHT

Having organized the data into the files just described, the required analyses were then conducted by successive searches of the files keyed on the particular categories or groups being compared. For example, for the comparison of groups 1 and 3, the files were searched for all AIDS recreated plans (which are identified by their group code) and, for those which were found to match on date, origin, destination, airline and flight number, the differences between the plan based on the forecast and the plan based on the actual were extracted and accumulated. (Note that no other parameters such as flight level, route or takeoff weight were matched.) The forecast plan value minus the actual plan value was saved for: fuel burn, flight time, air miles, ground miles, and the ratio of air miles to ground miles. These values were printed for each flight included in the analysis along with the mean difference, the variance, standard deviation, 90 percent confidence limits and number of occurrences. These data were printed in a format similar to the sample in Figure 4-3 which includes a histogram showing the frequency of occurrence of different values in ten unit increments. Each asterisk represents ten occurrences of that value.

In addition to these data, the average time, burn, air miles, ground miles, and ratio for all flights included in the analysis were printed.

The results were output for each comparison by airline (BLUE or RED), in total and by region, and by direction.

4.3 COMPARISONS BY SEGMENT

For the comparisons by segment a similar, nearly identical, procedure was used. The only difference was that it was required that the segment "From Point", "To Point" and flight level match along with the date, origin, destination, airline and flight number for the segment to be included in the analysis. (Again, note that a weight match was still not required.)

Since both computer systems feature the capability to perform a free search of available routes, within a limited number of input constraints,

Figure 4-3

SAMPLE OUTPUT

```
300                                +
290
280
270
260
250                                +
240
230
220
210
200                                +
190
180
170
160
150                                +
140
130
120
110                                *
100                                +
 90                                *
 80                                *
 70                                *
 60                                *
 50                                +
 40                                *
 30                                ***
 20                              *****  *  *
 10                        * ******************  *
      ----+----+----+----+----+----+----+----+----+----+----+
              -20       -10        0        +10       +20
```

Mean	2.16
Variance	34.61
Standard Deviation	5.88
90% Confidence Limits	-7.52 to 11.84
Total Occurrences	384

Total Fuel Consumed -Hundreds
Operational Forecast Vs. Re-Analysis

Carrier: BLUE   Direction: Eastbound   Region: All it was to be expected that different routes would be selected even when the weather conditions differed only slightly. As a result this additional requirement that the from point and to point match when a plan based on the forecast and a plan based on the actual were compared, large numbers of segments were rejected from the analysis.

Results of the segment comparisons were printed in similar format by airline, region and flight direction.

4.4 ADDITIONAL ANALYSES

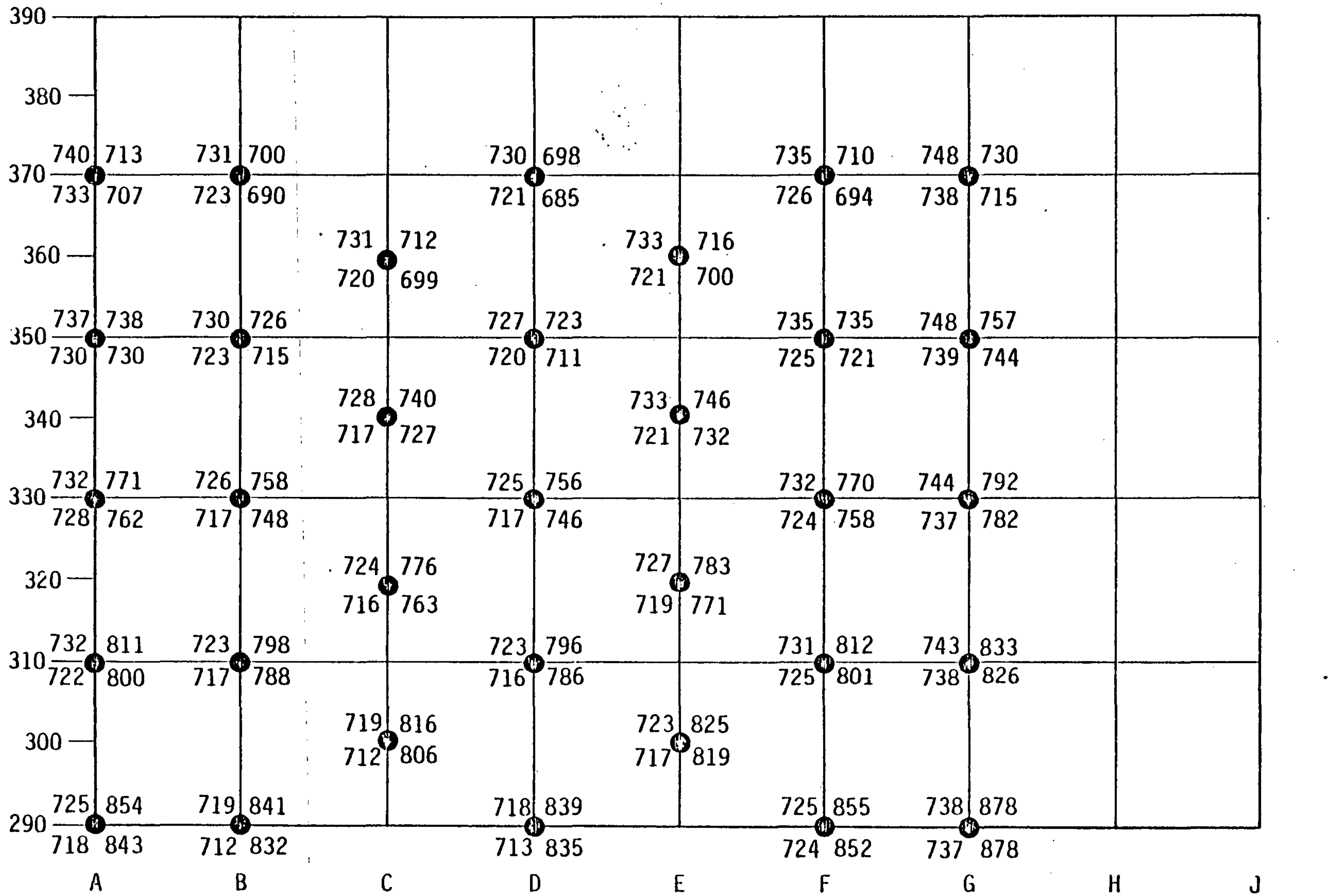
Several additional analyses were conducted manually since it was decided that the programming effort required to accomplish them automatically was rather complex for a program that would be used only once. These comparisons involved the North Atlantic Organized Track System, the fixed routing between Amsterdam and Caracas, and the method these airlines used in selecting which route was optimum on any given day.

Based upon a listing of summary information (date, flight, time, burn, etc.) for each flight plan that was stored in the flight totals data file, flight time and fuel burn from plans based on the forecast and the actual were plotted on a cross-sectional depiction of the NAT Tracks. Figure 4-4 following is a sample of one of these charts. These data were extracted and plotted for each day, eastbound and westbound, for BLUE and for RED (when RED data were available for the same days as BLUE). Similar plots were made for flight plans on nine fixed tracks between

Figure 4-4

COMPARISON OF TIME AND BURN ON NORTH ATLANTIC ORGANIZED TRACKS
ON OPERATIONAL FORECAST AND ACTUAL WEATHER
(DAY TRACKS)

DATE______________



Source: Flight plans computed on BLUE flight planning system

Key:

TIME (Hrs & Min)		BURN (100 Kg)
Forecast	●	Forecast
Actual		Actual

Amsterdam and Caracas. It was expected that these comparisons would provide data on such things as the number of times the optimum routing on the forecast proved to be the optimum on the actual.

5. DISCUSSION OF FINDINGS

****

The computer output results of the Task I analyses have been provided to NASA separately, in hard copy and on magnetic tape. They represent the detailed findings of the analysis of all of the input data that were provided.

These data cannot be reproduced in this report but they will be presented in summary form and discussed in detail along with comments on the practical significance of the findings. The following text describes the findings of the flight totals comparisons, segment comparisons and the special analyses of the NAT Tracks and the Amsterdam-Caracas tracks.

5.1 AIDS FLIGHTS ON FORECAST AND VERIFYING ANALYSIS

In the first case reviewed, flight plans recreated from AIDS flights and based on the operational forecast were compared with similar plans based upon the verifying analysis. In the nomenclature introduced in Section 4 of this report, these are comparisons of Group 1 versus Group 3 plans.

It was expected that this comparison would show the potential savings in fuel that would result if the verifying analysis were available at the time flights are being planned, or in other words, if the 18-hour or 24-hour forecasts were always identical to the subsequent NWS analyses produced 18 or 24 hours later. Since all of the other flight planning parameters (route, flight level, etc.) are held constant, this comparison measures the difference between the NWS forecast and the verifying analysis, expressed in terms of fuel burn, flight time and air miles.

As mentioned earlier, there are differences in the data interpolation and flight plan calculation algorithms between the BLUE and RED systems. However, if one only compares BLUE data to other BLUE data and RED data to other RED data, these differences are removed and the comparisons truly represent a measure of the forecast accuracy.

All of the plans compared in this first case were recreated from actual AIDS flights that operated on the corresponding dates in 1979. Thus, the potential savings from improved forecasts are real and would not be adjusted for such factors as ATC restrictions or other delays.

5.1.1 BLUE Data

Figure 5-1 summarizes the findings of the comparisons of BLUE flight plans. A total of 222 flights were considered in the analysis of eastbound operations. Of these 109 were in the North Atlantic region.

Since the differences were obtained by subtracting the Group 3 flight plan value from the Group 1 flight plan value, positive values mean the flight would require less fuel, less time, etc. on the verifying analysis than it would on the forecast. Considering the westerly direction of the prevailing wind, positive values also imply, in general, that the wind

Figure 5-1

TASK I RESULTS
AIDS FLIGHTS ON FORECAST AND VERIFYING ANALYSIS (CASE 1)
BLUE DATA

(GROUP 1 VS. GROUP 3) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn (kg)	109	569	4607	679	-548 to 1685
	Time (mins)		3.1	13.3	3.7	-3.0 to 9.1
	Ratio		.00721	.07204	.00849	-.00675 to .02117
	Air Mi (nm)		24.5	814.1	28.5	-22.4 to 71.4
	Grnd Mi (nm)		0	0	0	0
Africa	Burn	11	-291	3554	596	-1271 to 686
	Time		-2.1	9.9	3.1	-7.2 to 3.0
	Ratio		-.00755	.26879	.01639	-.0344 to .0193
	Air Mi		-13.5	804.8	28.4	-60.2 to 33.2
	Grnd Mi		0	0	0	0
Polar	Burn	15	940	8197	905	-549 to 2429
	Time		4.6	14.6	3.8	-1.7 to 10.9
	Ratio		.00807	.05433	.00737	-.00406 to .02019
	Air Mi		34.7	1096.9	33.1	-19.8 to 89.2
	Grnd Mi		0	0	0	0
Mid Atlantic	Burn	1	0	0	0	0
	Time		0	0	0	0
	Ratio		0	0	0	0
	Air Mi		0	0	0	0
	Grnd Mi		0	0	0	0
Middle East	Burn	43	186	2091	457	-563 to 938
	Time		1.1	7.3	2.7	-3.3 to 5.5
	Ratio		.0033	.07928	.0089	-.0113 to .0179
	Air Mi		7.7	406.8	20.2	-25.5 to 40.9
	Grnd Mi		0	0	0	0
Pacific	Burn	9	222	3862	621	-800 to 1244
	Time		.8	7.3	2.7	-1.7 to 5.2
	Ratio		.00256	.11736	.0108	-.0156 to .0203
	Air Mi		8.4	727.4	27.0	-36.0 to 52.8
	Grnd Mi		0	0	0	0

Figure 5-1 (Continued)

(GROUP 1 VS. GROUP 3) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
Europe	Burn	17	-141	495	222	-507 to 225
	Time		-.9	3.	1.7	-3.8 to 1.9
	Ratio		-.00594	.11841	.01088	-.02384 to .01196
	Air Mi		-6.5	131.8	11.5	-25.5 to 12.4
	Grnd Mi		0	0	0	0
United States	Burn	17	82	1167	342	-481 to 645
	Time		.6	6.7	2.6	-3.7 to 4.9
	Ratio		.0067	.2063	.01436	-.0169 to .0303
	Air Mi		4	238.6	15.4	-21.3 to 29.3
	Grnd Mi		0	0	0	0
All Regions	Burn	222	369	3681	607	-995 to 1364
	Time		2.0	10.6	3.3	-3.4 to 7.4
	Ratio		.00526	.0973	.00987	-.0110 to .0215
	Air Mi		15.3	650.3	25.5	-26.6 to 57.2
	Grnd Mi		0	0	0	0

Figure 5-1 (Continued)

(GROUP 1 VS. GROUP 3) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn	143	-295	11640	1079	-2070 to 1480
	Time		-1.2	29.6	5.4	-10.1 to 7.8
	Ratio		-.0034	.15467	.01244	-.02386 to .01706
	Air Mi		-11.5	1862	43.2	-82.5 to 59.5
	Grnd Mi		0	0	0	0
Caribbean	Burn	4	-75	319	179	-369 to 219
	Time		-.3	1.2	1.1	-2.1 to 1.5
	Ratio		-.00175	.04819	.00694	-.0132 to .00967
	Air Mi		-3.5	55.3	7.4	-15.7 to 8.7
	Grnd Mi		0	0	0	0
Far East	Burn	5	-140	944	307	-645 to 365
	Time		.4	1.0	1.0	-1.2 to 2
	Ratio		-.0026	.0624	.00776	-.0154 to .0102
	Air Mi		-4.4	165	12.8	-25.5 to 16.7
	Grnd Mi		0	0	0	0
Africa	Burn	21	52	5739	758	-1195 to 1299
	Time		-0.05	21.5	4.6	-7.6 to 7.5
	Ratio		.00157	.425	.02062	-.0323 to .0355
	Air Mi		2.5	1236.9	35.2	-55.4 to 60.4
	Grnd Mi		0	0	0	0
Middle East	Burn	76	-114	4452	667	-1211 to 983
	Time		-.6	14.1	3.8	-6.9 to 5.7
	Ratio		-.00129	.09998	.01000	-.0177 to .0152
	Air Mi		-3.6	766	27.7	-49.2 to 42
	Grnd Mi		0	0	0	0
Pacific	Burn	3	267	8889	94	112 to 422
	Time		1	0	0	1 to 1
	Ratio		.00433	.00422	.00205	.00096 to .0077
	Air Mi		10.3	6.9	2.6	6.0 to 14.6
	Grnd Mi		0	0	0	0

Figure 5-1 (Continued)

(GROUP 1 VS. GROUP 3) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
Europe	Burn	24	54	1075	328	-540 to 594
	Time		-.2	4.1	2.0	-3.5 to 3.1
	Ratio		.00092	.23583	.01536	-.0243 to .0262
	Air Mi		1.4	222	14.9	-23.1 to 25.9
	Grnd Mi		0	0	0	0
United States	Burn	6	-216	1181	344	-782 to 350
	Time		-1.8	1.5	1.2	-3.8 to 0.2
	Ratio		-.01583	.36514	.01912	-.0473 to .0156
	Air Mi		12.5	233.9	15.3	-12.7 to 37.7
	Grnd Mi		0	0	0	0
Polar	Burn	23	313	8481	921	-1202 to 1828
	Time		2.6	21.6	4.7	-5.1 to 10.2
	Ratio		.003	.05678	.00754	-.0094 to .0154
	Air Mi		13	1141.6	33.8	-42.5 to 68.6
	Grnd Mi		0	0	0	0
All Regions	Burn	305	-140	8072	898	-1617 to 1337
	Time		-.6	20.8	4.6	-8.2 to 7.0
	Ratio		-.00184	.16429	.01282	-.0229 to .01925
	Air Mi		-4.8	1720	41.5	-73.1 to 63.5
	Grnd Mi		0	0	0	0

Source: BLUE Airlines Flight Plans and PRC Speas Analysis speeds are underestimated. Stronger westerly winds appear on the analysis than do on the forecast.

This was the case for most of the BLUE results. Negative burn and time differences resulted only for the African area and for Europe. Most of the African flights are more southbound than eastbound and the prevailing westerly wind would not necessarily produce a positive difference, if in fact one could consider the "prevailing wind" to be westerly in the equatorial latitudes of Africa. Similarly, many of the European flights were more southbound than eastbound, such as Frankfurt to Athens. This could explain the negative differences for Europe. However, analysis of individual flight plan segments showed persistent differences (almost every day) between the forecast and actual in Eastern Europe and the Middle East through Yugoslavia, Greece, Turkey, Iraq and Iran, and it may well be that there is some other explanation of poor forecast performance in this region.

The overall result for all 222 eastbound flights was an average difference in fuel burn of 369 kg per flight. The potential time savings averaged two minutes per flight.

For the 109 North Atlantic flights the potential savings were larger. Average fuel burn difference per flight was 569 kg and the potential time savings averaged 3.1 minutes per flight.

For the westbound comparisons the results were largely consistent with the eastbound findings. The analysis included 305 flights, of which 143 were on the North Atlantic. Time and fuel differences were mostly negative, again indicating underestimated wind speeds. Africa and Europe produced positive differences as expected. Ignoring the Pacific data which included only three flights, only the polar region proved to be inconsistent with the eastbound findings. For the 23 polar flights the time and fuel differences were positive, although less than the eastbound values (313 kg and 2.6 minutes vs. 940 kg and 4.6 minutes).

For all westbound flights the burn difference averaged -140 kg per flight and the time difference averaged -0.6 minutes. On the North Atlantic the burn difference averaged -295 kg and the time difference averaged -1.2 minutes.

It is interesting to note that, although they are consistent in sign, the eastbound and westbound results are not consistent in absolute value. It would appear that greater savings are possible eastbound. Since the objectives of this study are only to identify and comment on the potential savings, a complete explanation of this apparent inconsistency is beyond the scope of this study. However, it is speculated that the lesser differences westbound may indicate that there is a gradient to the forecast error with the magnitude of the error diminishing as it progresses from the area of maximum winds to lighter winds. Thus, eastbound flights which tend to seek the maximum winds are subject to larger forecast errors than westbound flights which tend to be in the lighter wind regions north or south of the area of maximum winds. This may also explain the positive values for westbound polar flights.

5.1.2 RED Data

Figure 5-2 summarizes the corresponding comparisons of the RED data. There were 95 eastbound RED flights included in the analysis, of which 91 were on the North Atlantic. There were 147 westbound flights and 136 of these were North Atlantic flights. The remainder of the RED data were from polar flights.

Twelve RED flight plan comparisons for eastbound flights on November 5th were removed from the original data base. All of the eastbound RED flights for that day had differences of up to five to ten times the standard deviation between the plan on the forecast and the plan on the verifying analysis. Closer inspection of all individual flight plan segments on the North Atlantic showed wind direction differences of 100 to 160 degrees and speed differences of 70 to 100 knots. It was decided that differences this large were unlikely and that the RED data for that day were somehow contaminated. By comparison only one North Atlantic segment of all the BLUE plans for that day showed a wind direction and speed difference of more than 30 degrees and ten knots on November 5th.

There were three other days for which there were both large differences for RED Airlines and substantial disagreement between the RED and BLUE

Figure 5-2

TASK I RESULTS
AIDS FLIGHTS ON FORECAST AND VERIFYING ANALYSIS (CASE 1)
RED DATA

(GROUP 1 VS. GROUP 3) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
All	Burn (kg)	95	384	22674	1014	-1386 to 2154
	Time (mins)		2.5	26.4	5.1	-11.5 to 16.5
	Ratio		.00528	.12585	.01122	-.01431 to .02487
	Air Mi (nm)		18.6	1595.6	39.9	-51.1 to 88.3
	Grnd Mi (nm)		0	14.6	3.8	-6.7 to 6.7
North Atlantic	Burn	91	354	22396	1008	-1393 to 2129
	Time		2.3	26.5	5.2	-6.6 to 11.3
	Ratio		.00513	.12935	.01137	-.01458 to .02483
	Air Mi		17.6	1599.8	40.00	-51.8 to 86.9
	Grnd Mi		0.05	15.0	3.9	-6.7 to 6.8
Polar	Burn	4	1078	18180	908	-756 to 2912
	Time		6.3	10.2	3.2	-0.2 to 12.7
	Ratio		.00875	.03369	.00580	-.00297 to .02047
	Air Mi		42.3	915.7	30.3	-18.9 to 103.4
	Grnd Mi		-1.3	4.7	2.2	-5.6 to 3.1

(GROUP 1 VS. GROUP 3) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
All	Burn	147	-371	72973	1819	-3364 to 2623
	Time		-1.3	75.8	8.7	-15.6 to 13.1
	Ratio		-.00377	.41480	.02037	-.03727 to .02973
	Air Mi		-14.1	5127.7	71.6	-131.9 to 103.7
	Grnd Mi		-1.2	243.5	15.6	-26.9 to 24.4
North Atlantic	Burn	136	-385	74562	1839	-3411 to 2641
	Time		-1.3	77.0	8.8	-15.7 to 13.2
	Ratio		-.00394	.43517	.02086	-.03826 to .03037
	Air Mi		-14.6	5253.6	72.5	-133.8 to 104.7
	Grnd Mi		-1.4	257.9	16.1	-27.8 to 25.1
Polar	Burn	11	-194	52585	1544	-2735 to 2347
	Time		-1.1	61.5	7.8	-14 to 11.8
	Ratio		-.00164	.15805	.01257	-.02232 to .01904
	Air Mi		-8	3530	59.4	-105.7 to 89.7
	Grnd Mi		.1	63.0	7.9	-13.0 to 13.2

Source: RED Airlines Flight Plans and PRC Speas Analysis results. However, the differences were not so large and extensive as to be clearly erroneous and they were left in the data base. These discrepancies could be the result of data processing differences between the BLUE and RED systems.

The RED results are comparable to and consistent with the BLUE data. Average differences per flight for the 95 eastbound operations were 384 kg and 2.5 minutes. For the 147 westbound flights the differences were -371 kg and -1.3 minutes. For the North Atlantic flights the eastbound differences were 354 kg and 2.3 minutes and for westbound operations the differences were -385 kg and -1.3 minutes. There were so few polar flights that they should not be considered as a separate category.

Note in Figure 5-2 that slight differences in ground distances were recorded for RED while the BLUE data always showed a zero difference in ground distance. This is a result of differences in the track specification technique in the two systems. NASA's inputs to the BLUE system specified the route in its entirety, even though a direct route was assumed between the origin and the first ocean point. Therefore the route was the same in the plans based on the forecast and the verifying analysis. The RED system selects the minimum fuel routing in a free search each time. So, even though the ocean points were specified and identical for the forecast plan and the analysis plan, the airways portion of the plan was the best route available on that weather data set and thus differed between the plan on the forecast and the plan on the analysis.

5.2 MINIMUM TIME TRACKS ON FORECAST AND THE VERIFYING ANALYSIS

Case two compared minimum time tracks (or minimum fuel tracks) based on the operational forecast to minimum time tracks on the verifying analysis. These were comparisons of Group 2 plans with Group 4 plans.

These comparisons were actually quite similar to those in the previous case. It was essentially a test of the accuracy of the forecast but using different types of routes. In Case 1, the AIDS routes represented actual operational tracks which, for example, on the North Atlantic were routes that were compatible with the NAT Tracks. Here, the MTTs represent the ideal routing for fuel efficiency but are often routes which cannot be followed entirely because of their incompatibility with ATC operational requirements.

So, as in Case 1, it was expected that this comparison would show the potential fuel savings that could result if the verifying analysis were available at the time the forecast was issued. Here, however, the resultant savings would be the sum of contributions from three factors. The savings would be partly the result of the improved forecast, but the remainder would be achieved partly from removal of the ATC restrictions on the use of the MTT and partly from the ability to select a new MTT on the verifying analysis.

5.2.1 BLUE Data

For this analysis a total of 229 minimum time track comparisons were included in the eastbound BLUE data. In the westbound analysis 231 comparisons were included. All are from the North Atlantic or Pacific regions where MTT selection is possible. In other regions operations are more or less restricted to airways and "MTT" selections are limited to a choice among several fixed routings. The results of this analysis are presented in Figure 5-3.

One westbound North Atlantic case and 11 eastbound cases were removed from the original data base for this analysis because the plans on the forecast weather were based on different flight levels from those on which the plans on the verifying analysis were based. One could argue that selection of a lower fuel consumption altitude profile is part of the benefit of improved weather forecast data and that data from these flights should be included in the results. However, since we cannot be sure that the differing altitudes were not merely the result of constraints imposed by the program algorithm and since we were trying to isolate the affects of weather forecast data on fuel consumption, these cases were not included.

As one might expect from the foregoing discussion the results of this analysis are largely consistent in sign and magnitude with the Case 1 results. The potential fuel and time savings for the 229 eastbound flights were 739 kg and 4.4 minutes. This is approximately twice the

Figure 5-3

TASK I RESULTS
MINIMUM TIME TRACKS ON FORECAST AND VERIFYING ANALYSIS (CASE 2)
BLUE DATA

(GROUP 2 VS. GROUP 4) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
All	Burn (kg)	229	739	5901	768	-524 to 2002
	Time (mins)		4.4	17.4	4.2	-2.5 to 11.2
	Ratio		.00996	.12951	.01138	-.00876 to .02868
	Air Mi (nm)		31.8	1002.8	31.7	-20.3 to 83.9
	Grnd Mi (nm)		-4.1	943.9	30.1	-54.6 to 46.5
North Atlantic	Burn	199	815	5319	729	-381 to 2011
	Time		4.8	15.5	3.9	-1.7 to 11.3
	Ratio		.01087	.12143	.01102	-.00726 to .02894
	Air Mi		34.8	921.5	30.4	-15.0 to 84.6
	Grnd Mi		-3.8	871.6	29.5	-52.4 to 44.7
Pacific	Burn	30	233	6829	826	-1122 to 1588
	Time		1.4	19.6	4.4	-5.9 to 8.7
	Ratio		.0039	.14089	.01187	-.01563 to .02337
	Air Mi		11.9	1084.2	32.9	-42.1 to 65.9
	Grnd Mi		-5.5	1421.1	37.7	-67.5 to 56.6

(GROUP 2 VS. GROUP 4) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
All	Burn	231	-409	15543	1246	-2459 to 1641
	Time		-2.0	40.3	6.4	-12.5 to 8.4
	Ratio		-.00194	.30611	.0175	-.02685 to .03073
	Air Mi		-17.2	2551.2	50.5	-100.3 to 65.9
	Grnd Mi		-21.1	2484.8	49.9	-103.1 to 60.9
North Atlantic	Burn	202	-322	13518	1163	-2235 to 1591
	Time		-1.7	37.8	6.2	-11.8 to 8.4
	Ratio		-.00348	.3205	.0179	-.02597 to .03293
	Air Mi		-14.3	2097.8	45.8	-89.6 to 61.1
	Grnd Mi		-24.2	2768.3	52.6	-110.7 to 62.4
Pacific	Burn	29	-1017	25421	1594	-3639 to 1605
	Time		-4.3	51.9	7.2	-16.1 to 7.6
	Ratio		-.00879	.1812	.01346	-.03093 to .01335
	Air Mi		-37.7	3348.6	57.9	-132.9 to 57.5
	Grnd Mi		0	0	0	0

Source: BLUE Airlines Flight Plans and PRC Speas Analysis savings noted for all regions in Case 1. For the 199 North Atlantic operations the potential savings were 815 kg and 4.8 minutes.

Again, the positive differences eastbound indicate wind speeds were underestimated in the forecast. The small negative differences in ground distance also support this conclusion. MTT selection is a tradeoff between air miles and ground miles. One is willing to go further away from the great circle, or shortest distance route, if favorable winds on that longer distance routing reduce the flight time or air miles. In this case, the negative ground distance differences imply that the route selection program is less inclined to search further away from the great circle in the underforecast or lighter winds. The stronger winds in the actual weather data set allow searching further from the great circle to utilize these beneficial winds at the expense of a larger ground distance.

For the 231 westbound flights the average differences in burn and time were -409 kg and -2.0 minutes. For the 202 North Atlantic operations the differences were -322 kg and -1.7 minutes. These results were also consistent with the previous findings. The differences were negative and smaller than the eastbound differences.

The negative differences in ground distance were four to five times larger than the eastbound differences. This is also consistent with the previous comment on ground distance. In the westbound case the track selection process tends to consider routings further from the underestimated maximum winds and thus, on the average, further from the great circle. When these selections are rerun on the verifying analysis the stronger winds force the selection still further from the great circle and result in the larger negative ground distance differences.

The results for the Pacific region merit some comment and explanation. For the 29 westbound flights on the Pacific the average burn difference was -1,017 kg and the time difference was -4.3 minutes. At first it would appear unusual that the differences on the Pacific are considerably larger. However, all of the Pacific flights considered were Seattle to Tokyo operations and the zero ground distance difference implies that the same track was used for the plans on the forecast and the analysis. Airspace restrictions (over USSR airspace) and the related ATC restrictions (the preferred routing from Anchorage to Tokyo) limit the free search of the MTT selection program. Routings further north, over Siberia would usually be selected. However, the plans on the underestimated winds and the plans on the stronger actual winds could not go further north and, thus, the stronger winds resulted in larger burn differences.

5.2.2 RED Data

In the RED data there were 29 cases in each direction after the November 5th data were removed. These results are presented in Figure 5-4. All

Figure 5-4

TASK I RESULTS
MINIMUM FUEL TRACKS ON FORECAST AND VERIFYING ANALYSIS (CASE 2)
RED DATA

(GROUP 2 VS. GROUP 4) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
All	Burn (kg)	29	475	9849	668	-883 to 1593
	Time (mins)		3.5	13.8	3.7	-2.8 to 9.7
	Ratio		.00993	.12317	.0111	-.00864 to .0285
	Air Mi (nm)		24.3	816	28.6	-23.5 to 72.1
	Grnd Mi (nm)		-6.6	542.4	23.3	-45.5 to 32.4

GROUP 2 VS. GROUP 4) WESTBOUND

All	Burn	29	-324	5850	1135	-1868 to 1220
	Time		-1	32.5	5.7	-10.4 to 8.4
	Ratio		-.00186	.45377	.0213	-.03318 to .0369
	Air Mi		-12.3	2059.5	45.4	-87.0 to 62.4
	Grnd Mi		-17.1	1341.6	36.6	-77.4 to 43.1

Source: RED Airlines Flight Plans
PRC Speas Analysis

of the minimum time tracks (or minimum fuel tracks, in this case) were from North Atlantic flights.

Eastbound the average differences were 475 kg of fuel and 3.5 minutes. Westbound the burn difference was -324 kg and the time difference was -1 minute. Again, these findings are completely consistent with the previous data and the same comments apply. The eastbound differences are positive, the westbound differences are negative and smaller, and the ground distance differences are negative but larger in the westbound case.

5.3 AIDS FLIGHTS AND MINIMUM TIME TRACKS ON FORECAST WEATHER

The third case analyzed, compared AIDS recreated flight plans on the forecast weather to minimum time tracks on the forecast, or Group 1 plans with Group 2 plans.

Since both plans in this case are based on the forecast, the comparison does not show directly the potential fuel savings that can be achieved through improved forecasts. Instead, this comparison was designed to show the savings that could be achieved, even with current forecast capability, if carriers were able to fly the optimum route or minimum time track and were not restricted by ATC operational constraints. Indirectly this was a test of the potential benefit from improved forecasting capability in that, were the forecasts available on a timely basis, weather considerations could be more effectively integrated into the process of defining the ATC constraints.

As was mentioned in Section 3, several inherent features of the BLUE system and the input procedures somewhat corrupted the results. While the RED data did not suffer from any such problems, there were so few RED cases that the RED data on their own could not be considered statistically reliable.

5.3.1 BLUE Data

Comparisons were made for 36 eastbound BLUE cases and 49 westbound flights, all on the North Atlantic. The findings are summarized in Figure 5-5.

The potential savings, eastbound, were 511 kg and -6.4 minutes. Westbound the savings were 1,978 kg and -7.4 minutes. However, these results must be adjusted for the effect of two factors - differing ground distances and differing flight levels.

The routings used for the AIDS recreated flight plans were only specified in detail for the over-ocean portion of the route. Direct routings were assumed for the segment between the origin and the first ocean checkpoint and the segment between the last ocean point and the destination. The minimum time track routing was restricted to usable airways routings for

Figure 5-5

TASK I RESULTS
AIDS FLIGHTS AND MINIMUM TIME TRACKS ON FORECAST WEATHER (CASE 3)
BLUE DATA

(GROUP 1 VS. GROUP 2) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn (kg)	36	511	32504	1803	-2455 to 3477
	Time (mins)		-6.4	53.3	7.3	-18.4 to 5.6
	Ratio		.00025	.00672	.04513	-.0108 to .0113
	Air Mi (nm)		-35.0	3092.3	55.6	-126.5 to 56.5
	Grnd Mi (nm)		-38.9	2579.9	50.8	-122.4 to 44.7

(GROUP 1 VS. GROUP 2) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn	49	1978	55846	2363	-1909 to 5865
	Time		-7.4	63.3	8.0	-20.5 to 5.7
	Ratio		-.00176	.37014	.01924	-.03341 to .02989
	Air Mi		-45.6	3140.8	56.0	-137.8 to 46.6
	Grnd Mi		-39	6125.5	78.3	-167.8 to 39.3

Source: BLUE Airlines Flight Plans
PRC Speas Analysis

these segments. This resulted in a distance bias favoring the AIDS recreated flight.

This discrepancy is further evident from the negative differences in both ground distance and air distance. From the discussion in Section 5.2.1 regarding MTT selection as a tradeoff between ground miles and air miles, it is apparent that one is willing to incur increasing penalties in ground miles in order to reduce air miles. The results of Figure 5-5, however, show that these AIDS flights incurred penalties both in air miles and ground miles.

Since the additional ground distance is added to the MTT, the result would be to increase the fuel savings were we able to quantify the ground distance error. To do so, the detailed segment by segment flight plan distances were compared for each of the routings that were used by the 36 eastbound and 49 westbound flights. Eastbound the average differences in ground distance between the airways routes and the direct routes actually used ranged from 3 nm for Montreal-Copenhagen flights to 114 nm for Houston-Amsterdam flights. Westbound the differences ranged from 4 nm between Copenhagen and Chicago to 70 nm between Amsterdam and Houston. The weighted average distance bias for all eastbound flights was 53 nm and for westbound flights it was 32.8 nm. Since most of the distance error occurred on the North American side where the overland routings are longer, it was decided that a correction factor based on the fuel flow for a heavier aircraft (early in its flight) would be used eastbound, and one based on a lighter aircraft (near the end of its flight) would be used westbound. Based on the actual fuel flows for the first one-third and last one-third of the flight, correction factors of 18 kg/nm (westbound) and 21 kg/nm (eastbound) were chosen. Applying these to the distance errors would add 1113 kg (53 nm x 21 kg/nm) eastbound, and 590 kg (32.8 nm x kg/nm) westbound to the estimated fuel savings presented in Figure 5-5.

A second modification of these results is suggested by differences in the planned flight levels for each group. NASA attempted to recreate the AIDS flights as closely as possible and restricted the flight plan altitudes to those used on the original flight. The minimum time track plans, however, were calculated at optimum flight levels. As a result, only two of the 36 eastbound cases and seven of the 49 westbound cases were at reasonably similar if not identical flight levels. For all others the MTT plan was at higher levels for some part of the flight.

Since one would normally use optimum flight levels on the MTT, if he could, this flight level discrepancy does not negate the conclusion. It's still correct to say that the 1,343 kg to 2,962 kg of fuel could have been saved had these AIDS flights flown the MTT at optimum altitude. However, some portion of the savings is the result of removal of restrictions on the use of the optimum altitudes and these savings would presumably be achieved even on the AIDS route if optimum altitudes were used.

The negative time differences in Figure 5-5 are another indication of the magnitude of the affect these flight level differences had on the result. If comparable flight levels were used (and the ground distance discrepancy were not present) it would be highly unlikely that a positive fuel burn difference and a negative time difference would result.

It was determined through analysis of the detailed flight plans that on the average the flight level differences occurred for the following percentages of the flight distance:

	Eastbound	Westbound
Same Flight Level	55%	34%
MTT 2000 Ft. Higher	8%	20%
MTT 4000 Ft. Higher	30%	33%
MTT 6000 Ft. Higher or More	7%	13%

Based upon the fuel mileage performance for a B747-200B, at long range cruise, and at standard temperature approximate fuel burn differences per nautical mile were determined between the optimum flight level and flight levels 2000, 4000 and 6000 ft. below optimum for the typical BLUE Airlines flight which had a landing weight of 204,000 kg and a takeoff weight of 280,000 kg (eastbound) to 293,000 kg (westbound). The weighted average difference in burn due to the flight level differences was found to be 0.3155 kg/nm westbound and 0.149 kg/nm eastbound. After applying this to the average eastbound flight of 3780 nm and the average westbound flight of 3712 nm it was estimated that 563 kg of the potential savings, eastbound, and 1171 kg of the potential savings, westbound, were the result of the flight level differences rather than routing or weather data.

In summary, one can estimate that the potential fuel savings in Case 3 could be as high as 1061 kg to 1397 kg after adjustments are applied as follows:

	Eastbound	Westbound
Fuel Savings (From Figure 5-5)	511 kg	1978 kg
Estimated Effect of Distance Bias	+1113 kg	590 kg
Estimated Effect of Flight Level Differences	-563 kg	1171 kg
Net Potential Savings	1061 kg	1397 kg

5.3.2 RED Data

Results for the RED data are presented in Figure 5-6. After the erroneous data for November 5th were removed, there were seven eastbound cases and 10 westbound.

The average savings, eastbound, were 1,892 kg and 2.9 minutes, and for westbound operations, 1,760 kg and 1.7 minutes. In this case the distances and flight levels were comparable and, except for the effect of the small sample size, these results are representative of the potential savings.

Figure 5-6

TASK I RESULTS
AIDS FLIGHTS AND MINIMUM TIME TRACKS ON FORECAST WEATHER (CASE 3)
RED DATA

(GROUP 1 VS. GROUP 2) EASTBOUND

	Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic Burn (kg)	7	1892	42828	1394	-400.6 to 4186
Time (mins)		2.9	27.8	5.3	-5.8 to 11.5
Ratio		.014	.16943	.01302	-.00741 to .03541
Air Mi (nm)		42.9	1879	43.4	-28.5 to 114.2
Grnd Mi (nm)		-.6	243.1	15.6	-26.2 to 25.1

(GROUP 1 VS. GROUP 2) WESTBOUND

	Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic Burn	10	1760	41142	1366	-487 to 4008
Time		1.7	6.6	2.6	-2.5 to 5.9
Ratio		.00710	.12249	.01107	-.01111 to .02531
Air Mi		24.6	179.8	13.4	2.5 to 46.7
Grnd Mi		3.4	1532.6	39.2	-6.1 to 67.8

Source: RED Airlines Flight Plans
PRC Speas Analysis

5.4 AIDS FLIGHTS AND MINIMUM TIME TRACKS ON THE VERIFYING ANALYSIS

The fourth case analyzed compared AIDS recreated flights on the verifying analysis to minimum time tracks on the same weather data. These were Group 3 plans compared to Group 4 plans.

This case is essentially the same as Case 3 except for the weather data used. It is still a comparison of flights on actual operational routes with flights on the optimum route for that weather data set. The weather data is the same for both flight plans but this time it is the verifying analysis rather than the forecast. In fact, if one were to think of the weather data as a "black box" regardless of whether it is forecast or analysis, the conditions for this comparison are identical to those in Case 3 except that a different "black box" has been substituted for the weather.

As such, Case 4 is another measure of the potential savings which could be achieved if carriers could fly the MTT at optimum flight levels. Unfortunately, the same conditions regarding ground distance and flight level differences existed here and these results are also somewhat misleading. Only three of the eastbound and five of the westbound BLUE Airlines flights had comparable flight levels.

5.4.1 BLUE Data

Thirty-five eastbound and 48 westbound North Atlantic BLUE flights were included in the Case 4 comparison. These findings are presented in

Figure 5-7 and, as would be expected, they are comparable in sign and magnitude to the Case 3 results. Burn differences are positive indicating a potential fuel savings, and time, air distance, and ground distance differences are negative, indicating discrepancies in the ground distances and flight levels.

For the 35 eastbound flights the potential fuel savings were 666 kg and the time difference was -6.5 minutes. For the 48 westbound flights the burn and time differences were 2,096 kg and -7.5 minutes.

Following the same methodology as in Case 3, the effect of the ground distance and flight level differences can be estimated. Since the same city pairs are involved, it can be assumed that the bias introduced because of the distance and flight level differences is the same, on the average, even though the routes and flight levels for individual flights may differ.

Therefore, as in the previous case, we must conclude that the potential fuel savings presented in Figure 5-7 should be adjusted as follows:

	Eastbound	Westbound
Fuel Savings (From Figure 5-7)	666 kg	2096 kg
Estimated Effect of Distance Bias	+1113 kg	590 kg
Estimated Effect of Flight Level Differences	-563 kg	1171 kg
Net Potential Savings	1216 kg	1515 kg

Figure 5-7

TASK I RESULTS
AIDS FLIGHTS AND MINIMUM TIME TRACKS ON THE VERIFYING ANALYSIS (CASE 4)
BLUE DATA

(GROUP 3 VS. GROUP 4) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn (kg)	35	666	30067	1734	-2172 to 3532
	Time (mins)		-6.5	48.5	7.0	-18 to 5
	Ratio		.00388	.13042	.01142	-.01524 to .02233
	Air Mi (nm)		-30.8	2636.2	51.3	-114.8 to 54.1
	Grnd Mi (nm)		-48.1	2604.1	51.0	-133.7 to 34.2

(GROUP 3 VS. GROUP 4) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn	48	2096	61579	2482	-1986 to 6178
	Time		-7.5	99.3	10.0	-23.9 to 8.9
	Ratio		.00538	1.10811	.03329	-.04938 to .06014
	Air Mi		-43.5	5490.7	74.1	-165.4 to 78.4
	Grnd Mi		-61.2	9137.7	95.6	-218.4 to 96.1

Source: BLUE Airlines Flight Plans
PRC Speas Analysis

5.4.2 RED Data

The corresponding RED results for Case 4 are presented in Figure 5-8. Again, the data for the eastbound flight of November 5th have been removed to be consistent with the previous comparisons.

The average burn and time differences for the seven eastbound flights were 1,931 kg and three minutes. For the ten westbound flights the differences were 1,937 kg and 2.8 minutes. These results are quite similar to the RED results in the previous case, as one would expect since only the weather data set differed between the two.

5.5 AIDS FLIGHTS ON FORECAST WEATHER AND MTTs ON THE VERIFYING ANALYSIS

The fifth case compared AIDS recreated flights on the forecast weather to minimum time tracks on the verifying analysis, or Group 1 plans to Group 4 plans.

In effect this case combines the conditions of the two previous cases. It was expected that it would show the combined savings that could be achieved from an improved forecast and from being permitted to fly the MTT at optimum flight levels. As such, it represents the maximum savings that could be achieved as measured by the current NWS analysis and forecast models. It compared flights as they are typically operated in the real world today with flights as they might be operated under ideal conditions.

Figure 5-8

TASK I RESULTS
AIDS FLIGHTS AND MINIMUM FUEL TRACKS ON THE VERIFYING ANALYSIS (CASE 4)
RED DATA

(GROUP 3 VS. GROUP 4) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn (kg)	7	1931	40405	1354	-296 to 4159
	Time (mins)		3	16.3	4.0	-3.6 to 9.6
	Ratio		.01729	.07020	.00838	.0035 to .03107
	Air Mi (nm)		42.4	1083.4	32.9	-11.7 to 96.6
	Grnd Mi (nm)		-11.6	229.1	15.1	-36.5 to 13.3

(GROUP 3 VS. GROUP 4) WESTBOUND

North Atlantic	Burn	10	1937	55073	1581	-663 to 4538
	Time		2.8	16.2	4.0	-3.8 to 9.4
	Ratio		.0156	.63924	.02528	-.02599 to .05719
	Air Mi		34	794.4	28.2	-12.4 to 80.4
	Grnd Mi		-12.8	3494.2	59.1	-110.0 to 84.4

Source: RED Airlines Flight Plans
PRC Speas Analysis

Since this comparison was between AIDS flights and MTTs it was also subject to the discrepancies introduced due to the direct routings and the flight level differences. Only four of the eastbound and seven of the westbound BLUE flights were at comparable flight levels.

5.5.1 BLUE Data

Thirty-six eastbound and 49 westbound flights were included in the BLUE data for Case 5. The results of the analysis are presented in Figure 5-9. For the eastbound flights the average fuel savings were 1311 kg and the time difference averaged -2.6 minutes. For the westbound flights the average fuel savings were 1594 kg and the time difference was -9.0 minutes.

As in the previous cases, the effect of the direct distances and flight level differences was added.

	Eastbound	Westbound
Fuel Savings (From Figure 5-9)	1311 kg	1594 kg
Estimated Effect of Distance Bias	+1113 kg	590 kg
Estimated Effect of Flight Level Differences	-563 kg	-1171 kg
Net Potential Savings	1861 kg	1013 kg

It follows from the discussion above that the potential savings achieved should be greater in Case 5 than in any of the previous cases reviewed. Based on the adjusted figures the eastbound difference or potential

Figure 5-9

TASK I RESULTS
AIDS FLIGHTS ON FORECAST WEATHER AND MTTS ON THE VERIFYING ANALYSIS (CASE 5)
BLUE DATA

(GROUP 1 VS. GROUP 4) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn (kg)	36	1311	37382	1933	-1861 to 4500
	Time (mins)		-2.6	72.3	8.5	-16.4 to 11.6
	Ratio		.01183	.21714	.01474	-.01274 to .03574
	Air Mi (nm)		-2.0	3958.5	62.9	-105.3 to 101.7
	Grnd Mi (nm)		-51.2	2533.2	50.3	-132.7 to 32.9

(GROUP 1 VS. GROUP 4) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn	49	1594	60316	2456	-2446 to 5634
	Time		-9.0	102.8	10.1	-25.7 to 7.6
	Ratio		.00206	.82296	.02869	-.04513 to .04925
	Air Mi		-60.1	5754.3	75.9	-185.3 to 64.3
	Grnd Mi		-65.9	9404.8	97.0	-225.4 to 93.7

Source: BLUE Airlines Flight Plans
PRC Speas Analysis

fuel savings of 1861 kg are the highest of any of the cases reviewed. However, for the westbound flights the savings of 1013 kg are less than the westbound savings in the two previous cases.

5.5.2 RED Data

In Case 5 there were six eastbound and 10 westbound flights included in the RED data. Findings are summarized in Figure 5-10. As in the previous comparisons the suspected erroneous data for a flight on November 5th were removed before the statistics in Figure 5-10 were calculated.

The average savings in burn and time for the six eastbound flights were 1,989 kg and 6.8 minutes. The differences for the ten westbound flights were 1,220 kg. Again these potential savings are lower than those found for RED in the previous cases. However, this is probably the result of the statistical unreliability of the very small number of flights in the sample rather than an indication that no additional savings could be achieved through improved forecasts.

5.6 COMPARISONS BY SEGMENTS

Comparisons similar to those described for flight totals were made for individual flight plan segments. As mentioned in Section 4.3 dissimilar routes and flight levels resulted in vast numbers of segments being rejected from the analysis. As a result the segment results were not

Figure 5-10

TASK I RESULTS
AIDS FLIGHTS ON FORECAST WEATHER AND MFT'S ON THE VERIFYING ANALYSIS (CASE 5)
RED DATA

(GROUP 1 VS. GROUP 4) EASTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn (kg)	6	1989	29029	1148	100 to 3877
	Time (mins)		6.8	33.1	5.8	-2.7 to 16.3
	Ratio		.02467	.10856	.01042	.00753 to .04181
	Air Mi (nm)		66.7	1894.6	43.5	-5.0 to 138.3
	Grnd Mi (nm)		-10.2	293.8	17.1	-38.4 to 18.0

(GROUP 1 VS. GROUP 4) WESTBOUND

		Occurrences	Mean	Variance	Std. Dev.	90 Percent Confidence Limits
North Atlantic	Burn	10	1220	79115	1895	-1896 to 4337
	Time		-1.1	52.9	7.3	-13.1 to 10.9
	Ratio		.0049	.77089	.02776	-.04077 to .05057
	Air Mi		.6	3150.4	56.1	-91.7 to 92.9
	Grnd Mi		-13.7	3488.6	59.1	-110.9 to 83.5

Source: RED Airlines Flight Plans
PRC Speas Analysis

deemed to be meaningful and no attempt was made to adjust the computer findings to correct for any anomolies in the data.

Since all conditions were similar, the findings for segment data should have been consistent with the findings for the flight totals. The flight totals are merely the sum of the segments.

In Case 1, for example, the average ground distance for all eastbound BLUE flights was 2,545 nm. For the corresponding segment data the average distance was 213 nm. Therefore, on the average, there were 11.9 segments per flight and the average burn difference per segment of 14 kg times 11.9 segments should agree with the Case 1 difference for the flight totals of 569 kg. Of course it does not agree exactly but in terms of sign and order of magnitude the segment totals for this case, and for all the others, are generally in agreement with the flight total comparisons.

Where they do not agree, it is apparent that the segment data either consist of very small samples or the corrections for data anomalies have not been applied.

Summaries of the segment data appear in Figures 5-11 through 5-13.

Figure 5-11

TASK I RESULTS BY SEGMENT
AIDS RECREATED FLIGHTS ON FORECAST AND VERIFYING ANALYSIS (CASE 1)

	Occur-rences	Avg. Burn Diff. (kg)	Std. Dev.	AVERAGE DISTANCE Air Mi.	Grnd. Mi.
BLUE EASTBOUND					
All Regions	3013	14	182	201	213
North Atlantic	603	74	156	335	377
Caribbean	87	1	47	108	112
Far East	244	2	16	207	207
Africa	339	-1	71	180	182
Polar	132	-70	706	310	326
Middle Atlantic	179	-18	113	266	265
Middle East	1228	5	84	128	131
Pacific	77	36	132	342	362
Europe	99	-13	77	80	82
North America	25	40	98	180	193
BLUE WESTBOUND					
All Regions	4403	-2	280	213	204
North Atlantic	809	-280	228	398	370
Caribbean	46	2	39	91	91
Far East	594	-5	64	183	178
Africa	510	-4	58	127	125
Polar	197	126	1144	356	353
Middle Atlantic	180	-4	193	473	467
Middle East	1810	-5	99	139	135
Pacific	19	32	172	444	432
Europe	213	5	64	83	80
North America	25	-60	123	125	109
RED EASTBOUND					
All Regions	1785	-7	470	163	179
North Atlantic	1647	-11	352	163	178
RED WESTBOUND					
All Regions	2387	-15	548	199	184
North Atlantic	2162	-16	572	198	183

Source: RED and BLUE Airlines Flight Plans and PRC Speas Analysis

Figure 5-12

TASK I RESULTS BY SEGMENT
MINIMUM TIME/MINIMUM FUEL TRACKS ON FORECAST AND VERIFYING ANALYSIS (CASE 2)

	Occur-rences	Avg. Burn Diff. (kg)	Std. Dev.	AVERAGE DISTANCE Air Mi.	AVERAGE DISTANCE Grnd. Mi.
BLUE EASTBOUND					
All Regions	1896	93	363	167	187
North Atlantic	1748	97	375	156	174
BLUE WESTBOUND					
All Regions	1823	-2	918	222	207
North Atlantic	1493	20	1005	197	187
RED EASTBOUND					
North Atlantic	210	74	747	160	179
RED WESTBOUND					
North Atlantic	176	-7	160	171	157

Source: BLUE and RED Airlines Flight Plans
PRC Speas Analysis

Figure 5-13

TASK I RESULTS BY SEGMENT
AIDS RECREATED FLIGHTS AND MTT/MFT ON FORECAST AND VERIFYING ANALYSIS

	Occurrences	Avg. Burn Diff. (kg)	Std. Dev.	AVERAGE DISTANCE Air Mi.	AVERAGE DISTANCE Grnd. Mi.
CASE 3 - AIDS AND MTT ON FORECAST					
BLUE Eastbound					
All Regions	9	56	164	280	311
BLUE Westbound					
All Regions	18	133	231	275	261
RED Eastbound					
North Atlantic	14	3	36	134	146
RED Westbound					
North Atlantic	24	-25	59	143	126
CASE 4 - AIDS AND MTT ON ANALYSIS					
BLUE Eastbound					
All Regions	4	150	206	264	294
BLUE Westbound					
All Regions	8	175	259	251	235
RED Eastbound					
North Atlantic	4	-34	38	64	62
RED Westbound					
North Atlantic	14	-13	36	126	112
CASE 5 - AIDS ON FORECAST AND MTT ON VERIFYING ANALYSIS					
BLUE Eastbound					
All Regions	3	200	245	244	275
BLUE Westbound					
All Regions	8	163	250	251	234
RED Eastbound					
North Atlantic	4	-23	39	57	60
RED Westbound					
North Atlantic	14	-32	72	128	114

Source: BLUE and RED Airlines Flight Plans and PRC Speas Analysis

5.7 NORTH ATLANTIC ORGANIZED TRACKS

BLUE flight plans were run on each NAT Track at each available flight level from 290 to 370 for the 30 days for which data were collected. These plans were run both on the forecast and on the verifying analysis. Corresponding data were available from RED for eight of the "eastbound days" and 16 of the "westbound days".

In routine daily operations it is not practical for an airline to compute a flight plan for every NAT Track at every available level to determine the least fuel route and profile to use on that day. Therefore, track selection systems were developed that would search for the approximate least fuel track, so that a small number of plans could be run to determine the best route. Each system uses some assumptions to shorten the search and, although computer track selection has been in use for nearly 20 years, there is still wide disagreement on which method is best and which assumptions introduce the least error.

Among others, there are three track selection assumptions inherent in airline flight planning systems which could be tested in this analysis.

The first assumption is that the minimum fuel track and the minimum time track are identical. Airline systems following this assumption select an MTT in a preliminary analysis and then expect that the minimum fuel plan is a vertical optimization on that track.

A second assumption used by some airlines is that there is no significant track selection difference in the vertical, or in other words, the minimum time route selected at FL330 would also be the minimum time route at FL290 or FL390.

A third widespread belief, although it is not incorporated directly into flight planning algorithms, is that synoptic scale systems change slowly enough so that the choice of the best NAT Track does not change between forecast and actual even though the time and fuel burn might change. For example, if Track C is selected as the best on the forecast it will continue to be best through the verification time.

Each of these three theories was tested in this analysis.

The first case considered, which attempted to determine whether the minimum time NAT Track and minimum fuel NAT Track were the same, could be analyzed both on the forecast weather and on the verifying analysis.

For BLUE JFK-AMS and AMS-JFK track comparisons on the forecast weather data, the minimum time NAT track was coincident with the minimum fuel track 36 out of a possible 60 times (one eastbound and one westbound case on each of 30 days). The minimum fuel track was on the track adjacent to the minimum time track 20 times and on the remaining four occasions it was displaced by two tracks, which could be 120 or 240 nautical miles away depending on whether or not composite tracks were in use.

On the verifying analysis, the tracks were coincident 27 times. The minimum fuel track was adjacent to the minimum time track 28 times and was displaced by two tracks on the remaining five occasions.

With the RED data the findings were similar. Comparisons of the track selection were made for 16 westbound days and eight eastbound days. On the forecast weather the minimum time track was coincident with the minimum fuel track 13 times and on the adjacent track 11 times. Once, the minimum time and minimum fuel tracks were displaced by five tracks with the MTT being Track D and the MFT being Track H. On the verifying analysis, the findings were almost identical with 13 on the same track, 11 on the adjacent track and one day on which the MTT and MFT were separated by two tracks.

Based on these data it is clear that airlines that use minimum time as the basis for their track selection algorithm are not selecting the best fuel track nearly 50 percent of the time.

To test the second hypothesis, the minimum time NAT track selected by the BLUE system at FL330 eastbound and FL350 westbound were compared to the minimum fuel track which was invariably at one of the higher flight levels available in the system. Minimum time tracks from the forecast were compared to minimum fuel tracks on the analysis. For 32 of the 60 cases the NAT minimum time track selected at FL330 or FL350 was also the minimum fuel track. For 20 flights the MFT was the track adjacent to the MTT and the average burn penalty for being on the wrong track was 205 kg. (This was determined by subtracting the burn on the MFT flight plan from the burn on the plan that was based on the MTT at optimum flight levels.) The MFT was displaced two NAT tracks from the MTT on three days with an average burn penalty of 367 kg. On four days the displacement was three tracks with a penalty of 308 kg and for the one remaining case the displacement was four tracks with a penalty of 500 kg.

On the average, therefore, a penalty of 248 kg of fuel results each time the wrong track is selected and, considering all cases, an average penalty per flight of 116 kg results from basing the track selection on minimum time at a single flight level.

The third question was addressed by comparing the minimum fuel track on the forecast to the minimum fuel track on the verifying analysis. For 41 of the 60 BLUE flights both MFTs were on the same NAT track. Even though the earlier findings from Case 2 in Section 5.2 showed that North Atlantic flight plans on the verifying analysis differed by 409 kg to 815 kg from those on the forecast, the findings discussed here verify that 68 percent of the time the same track would be selected on either weather data set. In these cases, selection of the track on the forecast did not contribute to the fuel burn penalty that resulted from the inaccuracy of the forecast.

For the remaining 19 flights the MFT on the verifying analysis was on the track adjacent to the MFT on the forecast six times and was displaced by 2, 3, or 4 NAT tracks 13 times. The average fuel burn penalty for these 19 flights was 353 kg. Since this difference was determined from both plans on the analysis, rather than between the forecast and the analysis, this penalty may be considered to be in addition to the penalty resulting from the forecast inaccuracy. In other words, combining the data from Case 2 and these data implies that for 32 percent of North Atlantic flights a penalty of up to 815 kg of fuel results because of forecast inaccuracy and an additional penalty of 353 kg is incurred because the wrong track was chosen in the first place.

5.8 AMSTERDAM-CARACAS ROUTES

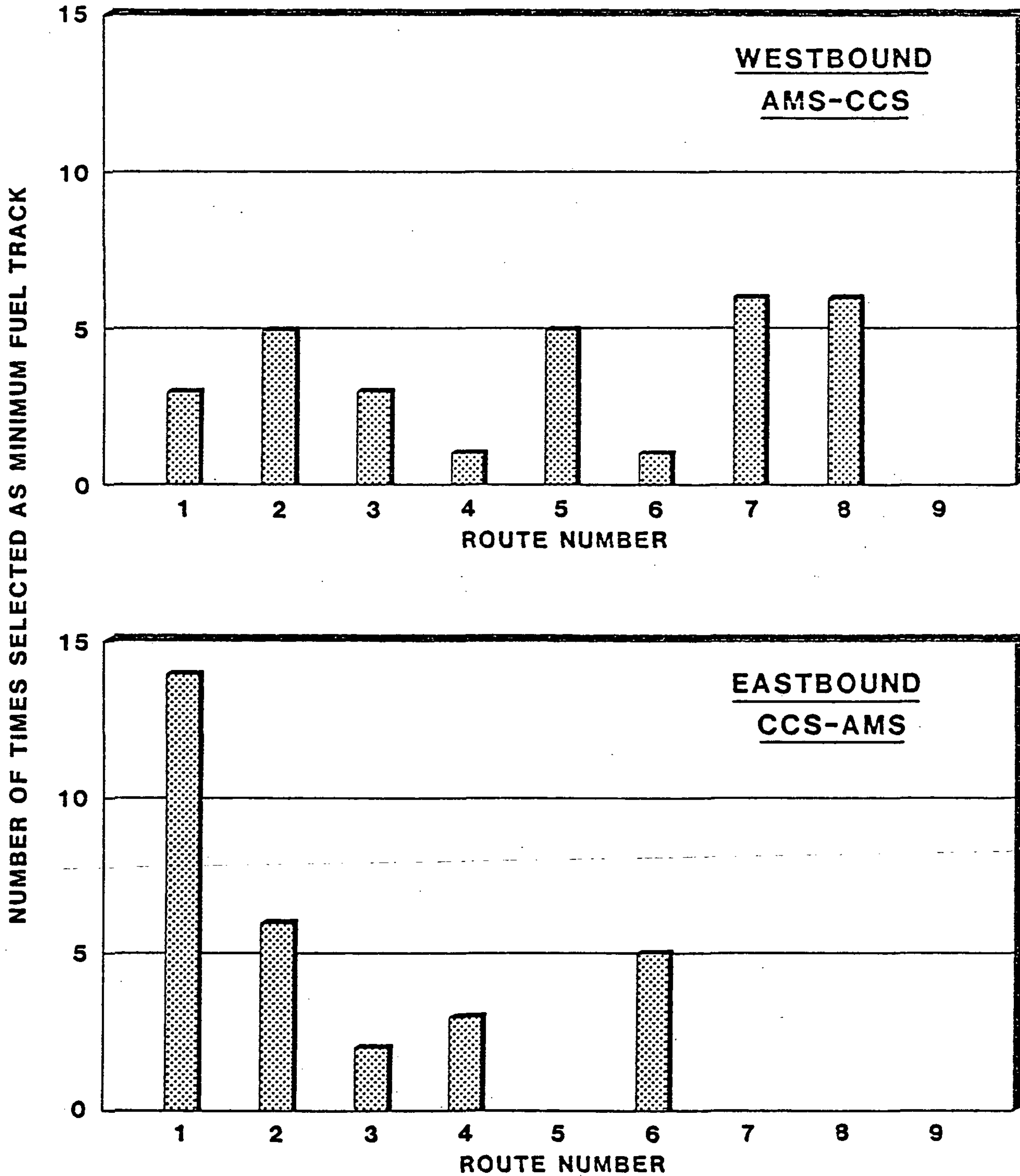
At the time these data were gathered it was the practice of at least one airline, and possibly more, to operate on a single fixed route between Europe and points in the Caribbean or the northern coast of South America. This was partly due to ATC considerations and partly due to the belief that a flight in the generally north-south direction, partly in southern latitudes, would not benefit much from an optimized track selection.

NASA arbitrarily laid out eight additional tracks some on each side of the fixed route, which was commonly referred to as "Red 99". Amsterdam-Caracas and Caracas-Amsterdam flight plans were run on the verifying analysis at all levels on each of these nine routes for each of the 30 days for which data were gathered.

Figure 5-14 shows the number of times each track was selected. Even without knowing which track was "Red 99", it is clear from the distribution of the choices that continuing to use a single fixed route between these cities is not wise. It turns out that track number 6 is the "Red 99" route and it was the best fuel choice only six times out of the 60 cases considered. The average burn and flight time differences between Track 6 and the actual best fuel route for each day were computed. These differences were 7.2 minutes and 1230 kg for the eastbound flights and 4.5 minutes and 877 kg for the westbound flights.

FIGURE 5-14

AMSTERDAM-CARACAS ROUTE SELECTION



SOURCE: PRC SPEAS ANALYSIS OF BLUE FLIGHT PLAN DATA