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Development of an Aircraft Approach and Departure Atmospheric Profile Generation Algorithm

Bill K. Buck and Steven G. Velotas
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June 2004

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1. Purpose of the Atmospheric Profile Generation Project

In support of the NASA Virtual Airspace Modeling and Simulation (VAMS) project, AeroTech has agreed to develop and test a technique for extracting meteorological data from landing and departing aircraft, and a technique for building, using the collected data, altitude based profiles for key meteorological parameters. The generated atmospheric profiles will be used as inputs to NASA's Aircraft Vortex Spacing System (AVOSS) Prediction Algorithm (APA) for benefits and trade analysis. A Wake Vortex Advisory System (WakeVAS) is being developed to improve aircraft spacing and therefore improve airport throughput, as well as to better model airports' airspace for the VAMS project. The purpose of this report is to document the initial theory and design of the Aircraft Approach & Departure Atmospheric Profile Generation Algorithm (referred to in the remainder of this document as 'Atmospheric Profile Generation Algorithm') developed by AeroTech Research while under contract to NASA.

2. Background

Growing concern over capacity limitations in the National Airspace System (NAS) have led to the hypothesis that improvements to the current methods of spacing aircraft may be able to significantly improve capacity in and out of airfields. Current wake vortex separation standards found in the Air Traffic Controller's Handbook [1] depend on the runway configuration, the type of operation (approach or departure), type of approach (visual, instrument, etc.), and relative size of aircraft in front of the aircraft of concern. These standards are built on worst-case criteria. Wake vortex avoidance rules that are sensitive to the environmental influences on wake behavior may provide more efficient spacing criteria than the current methods.

To explore this potential, in July 2000, NASA demonstrated a system called the Aircraft Vortex Spacing System (AVOSS), which used inputs from state-of-the-art field weather sensors, wake sensors, and a wake behavior prediction algorithm to provide dynamic wake-safe reduced spacing for single runway arrivals. "Using real-time data, the system averaged a 6% potential throughput increase over the current standards[2]." Based on these results, NASA began WakeVAS concept development to expand on the success achieved with AVOSS. The concept developed for the WakeVAS relies on a number of inputs and enabling technologies. One of these inputs is aircraft meteorological data. "Aircraft have the potential of measuring all the parameters of interest at a high resolution, under all weather conditions, over the entire region of interest, and thus represent the primary means of collecting weather information [2]." Research has shown that algorithms processing commercial aircraft systems data can be used to collect weather information in the en route environment. The feasibility of collecting data during approach and departure has been shown, but has not yet been evaluated or quantified for application to a future WakeVAS. AeroTech Research was contracted under VAMS to not only accomplish this, but also to develop a way of building altitude based profiles of four key meteorological parameters (wind speed, wind direction, static temperature, and turbulence in the form of Eddy Dissipation Rate (EDR or ε)) using aircraft data.

3. Atmospheric Profile Generation Algorithm Purpose and Design

A problem in trying to reduce aircraft wake spacing criteria lies in the fact that measurement profiles of static temperature, wind speed, wind direction, and EDR for a region of interest at resolutions required for wake prediction are not available from current operational systems. A properly equipped aircraft that is on approach to or taking off from an airfield should be able to make measurements of parameters of interest throughout the airport's airspace. Data collected from many aircraft could be combined into statistical profiles of each parameter on a per runway or entire airfield basis.

3.1 Atmospheric Profile Generation Algorithm Design Overview

The first step in the development of the Atmospheric Profile Generation Algorithm was to define the region of interest where meteorological data from aircraft needs to be collected. Since the ultimate goal of a WakeVAS is to improve aircraft spacing in and out of airfields and because wake turbulence is generally found on approaches and departures, the approach and departure corridors were determined to be of primary interest. Airfield meteorological stations already can collect data from the ground up to 30m typically, so the lower altitude bound for the algorithm's region of interest was set at 30m above ground level (AGL). NASA also provided the stipulation that the WakeVAS would be used only at Instrument Landing System (ILS) equipped airfields. Research on ILS approaches showed that they are basically the same for each airfield once the ILS glide slope is intercepted, so the glide slope intercept point was chosen as another defining point for the algorithm's region of interest. The glide slope intercept point is the point where aircraft intercept the ILS three degree slope and then follow a set descent into the airfield. For a majority of airfields, aircraft intercept the glide slope by an altitude of 600m (AGL). Based on descent rates, this puts the aircraft approximately three minutes out from the runway touchdown point.

The glide slope intercept trigger point for the Atmospheric Profile Generation Algorithm is difficult to identify for several reasons.

1. No discrete marker is available in a standard ship system data recording to identify when the intercept has been achieved.
2. It can be quite often the case that an aircraft may be off the glide slope by several hundred feet at the start of an approach to landing.
3. Visual Meteorological Conditions (VMC) also allow a pilot to make a visual approach to a runway, thereby not strictly following the glide slope.

To eliminate these problems, an assumption was made that discounting emergencies, aircraft that were lower than 600m AGL and greater than 30m AGL were either on approach or departure from ILS equipped airfields; therefore, 30m AGL and 600m AGL were used to define and bound the algorithm’s region of interest (Figure 1). This region conforms with the research put forth in [3].

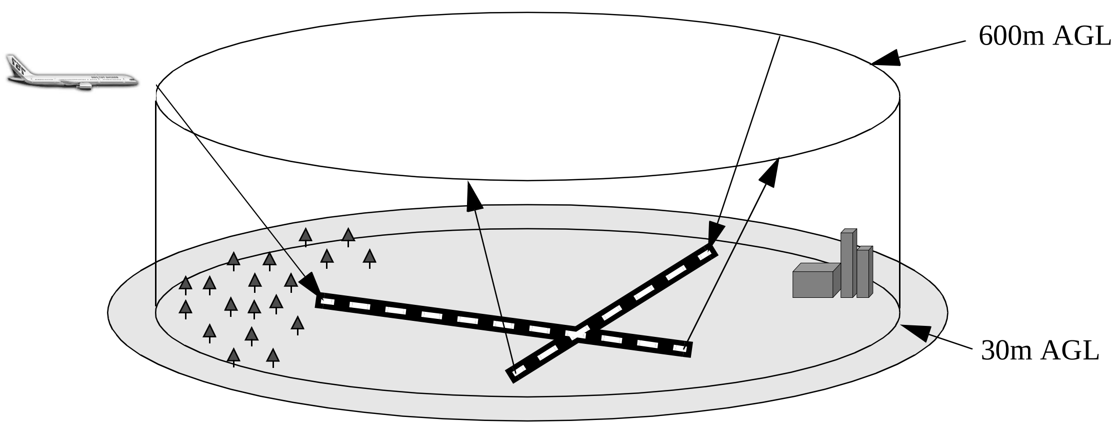

Figure 1: Airspace Cylinder Diagram, Approach and Departure

An Atmospheric Profile Generation Algorithm equipped aircraft would begin monitoring the system trigger at engine and aircraft systems start. Seven constants, listed in Table 1, have been built into the algorithm to define the data collection region and to allow for flexibility in testing and refinement of the algorithm in the future. Initial values for the constants are based on the determined region of interest and on inputs from AeroTech personnel, NASA managers, and NASA meteorologists.

Table 1: Atmospheric Profile Generation Algorithm Variable Constants

Variable	Description	Initial Value
$APGA_{STR}$	Altitude (barometric) to begin processing algorithms	3000 m
$APGA_{LOW}$	Lower Bound of Operation of the Algorithm (AGL)	30 m
$APGA_{HGH}$	Upper Bound of Operation of the Algorithm (AGL)	600 m
$APGA_{WNS}$	Sliding Window Size of Wind Speed Statistics Buffer	5 s
$APGA_{WND}$	Sliding Window Size of Wind Direction Statistics Buffer	5 s
$APGA_{EDR}$	Sliding Window Size of Eddy Dissipation Rate Statistics Buffer	20 s
$APGA_{TMP}$	Sliding Window Size of Static Temperature Statistics Buffer	5 s

When the barometric (baro) corrected altitude is below the criteria $APGA_{STR}$, the system begins the necessary calculations to be used in the statistics gathering (see Figure 2). At the altitude trigger $APGA_{HGH}$, the algorithm begins the buffering of the statistics data. As a sliding window period is passed for a particular parameter, the mean and median values of a particular buffer's content (Position and Temperature, Eddy Dissipation Rate, Wind Speed or Direction) are written to a file. As long as the aircraft is between the two altitude boundary points of $APGA_{HGH}$ and $APGA_{LOW}$, the system will continue to collect the data for all parameters using the predetermined sized statistics boxes. The algorithm stops statistics collection when the aircraft is below $APGA_{LOW}$. At this point, similar data would be independently collected from sensors mounted on stationary towers at the airfield. The same approach using the algorithm works for an aircraft on departure or on go-around conditions except that data buffering begins at 30m AGL (lower bound) and stops at 600m AGL (upper bound). It should be noted that fewer statistic data points may be gathered on departure given the climb out rate of an aircraft and the boundaries of the region of interest.

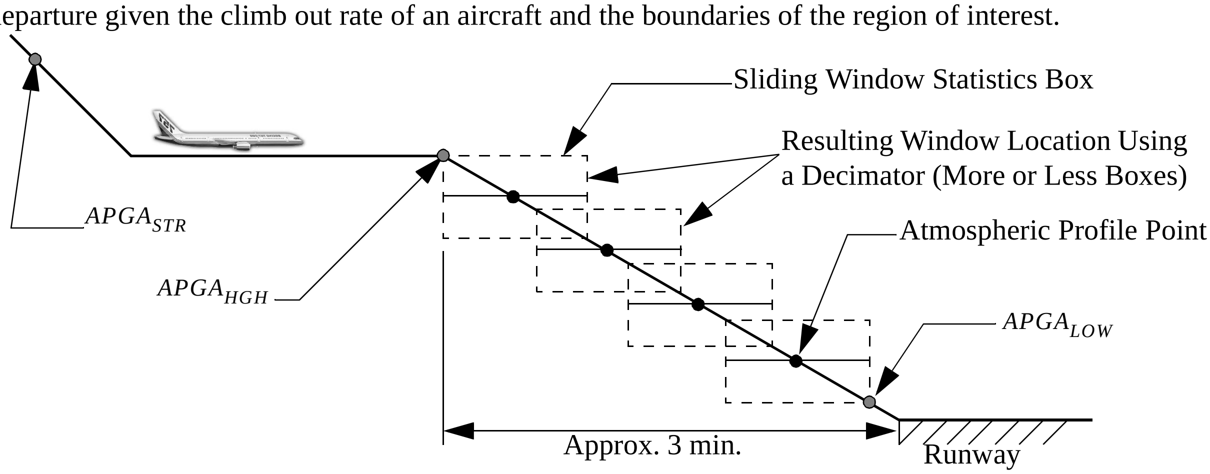

Figure 2: Atmospheric Profile Generation Algorithm Overview for an Approach Condition

For an actual WakeVAS implementation, the profiles from numerous landing and departing aircraft would be transmitted or downloaded in a manner to be defined to generate statistics on the parameters of interest.

These statistics would provide inputs to wake predictions from which aircraft spacing values could be computed in a manner similar to AVOSS. Weather prediction subsystems would also use the measured meteorological profiles as input.

At the request of NASA, a method of decimating the total number of data points in a generated profile to a manageable level has been included in the algorithm. For each parameter of interest, an associated selectable constant $(APGA_{WNS_{dcm}}$, $APGA_{WND_{dcm}}$, $APGA_{EDR_{dcm}}$, or $APGA_{TMP_{dcm}})$ can be set to take only a certain frequency of the available data from the statistics for generating the atmospheric profiles. Results presented in this document use a value of 100 for each of the decimator variable constants. This results in a value reported every one and half seconds for data at a research sample rate of 50Hz. This process reduces the total number of points for a possible research quality run from 10,000+ to approximately 100+ for each parameter.

3.2 Candidate Flight Data Set

To develop and test the Atmospheric Profile Generation Algorithm, a collection of data sets was identified for use during the Task 1 work. The NASA-LaRC Boeing 757-200 ARIES aircraft is the most accessible platform for high quality / high rate flight data, provides extensive research sensor capabilities, and is representative of a modern, subsonic commercial transport. It was determined that a candidate data set would require the following items:

- Current In Situ Algorithm developed for the NASA Turbulence Prediction and Warning Systems (TPAWS) program must be functioning and algorithm outputs recorded on the NASA-LaRC B757-200 during the flight experiments.
- Multiple approach and departure pattern work at a single airport should be included.
- The pattern work should be done over the course of several hours of the same day or night for consistency in building the parameters' profiles.
- Airfield meteorological data should be available, if possible.

Using the above criteria to search possible data sets, two flight tests were identified. Flight tests for NASA's Synthetic Vision Program [4] were performed in a manner that satisfied most of the criteria. Pattern work for the flights was performed at Dallas-Fort Worth (DFW) airport in Texas in the Fall of 2000, and at Eagle County Airport (EGE) in Colorado in the late Summer of 2001. Both flight tests satisfy the above requirements excluding the possibility of available meteorological data. Data from the DFW flight test was chosen because the possibility existed that meteorological data may have been collected at the field for the NASA AVOSS study during the same time period as the flight test. As work continued on Task 1, further investigation determined that no AVOSS meteorological data was available for the DFW flights, but the decision was made to continue testing and evaluation with the DFW flight data.

From the DFW flight test, two specific flight days were chosen based on the high number of approaches into, and departures from the airport. The two chosen dates were October 4, 2000, for flight R-162 (13 runs) and October 8, 2000, for flight R-165 (14 runs). Table 2 below lists specifics on each of the selected runs including date, time of run start and stop referenced to Greenwich Mean Time (GMT), and the runway approached.

Table 2: Candidate Data Sets Start and Stop Times

R162, October 4, 2000			
Run No.	Run Start (hh:mm:ss)	Run Stop (hh:mm:ss)	Runway
1	6:01:40	6:16:15	17C
2	6:17:05	6:32:05	17C
3	6:33:45	6:48:20	17C
4	6:56:40	7:08:20	17C
5	7:10:50	7:21:15	17C
6	7:25:30	7:36:40	17C
7	8:24:35	8:28:20	17C
8	8:31:40	8:45:25	17C
9	8:49:10	9:01:40	17C
10	9:04:35	9:18:20	17C
11	9:21:40	9:35:00	17C
12	9:40:00	9:52:05	17C
13	9:58:45	10:05:50	17C

R165, October 8, 2000			
Run No.	Run Start (hh:mm:ss)	Run Stop (hh:mm:ss)	Runway
1	5:30:25	5:41:15	35C
2	5:43:20	5:56:40	35C
3	5:57:30	6:08:20	35C
4	6:10:00	6:20:50	35C
5	6:21:40	6:32:50	35C
6	6:40:25	6:49:10	35C
7	6:51:15	6:56:40	35C
8	7:44:40	7:47:30	35C
9	7:49:10	7:59:10	35C
10	8:00:50	8:11:15	35C
11	8:12:30	8:22:55	35C
12	8:26:40	8:37:30	35C
13	8:40:00	8:49:10	35C
14	8:50:25	9:01:15	35C

4. Atmospheric Profile Generation Algorithm Assumptions

Several assumptions have been made in the development of the Atmospheric Profile Generation Algorithm. The values presented for many of the assumptions are used throughout the results presented in this paper.

- Eddy Dissipation Rate estimate will be made using derived inertial vertical winds.
- Trigger on approach is 600m (1968.5ft) AGL.
- Trigger on departure is 30m (98.4ft) AGL.
- Maximum height of interest is 600m AGL.
- Fixed length, sliding statistics window.
- Window length is 5 seconds for Wind Speed, Wind Direction and Temperature and 20 seconds for Eddy Dissipation Rate.
- Decimator size is 100 for the four parameters of interest.
- Input data files are properly formatted and aircraft data is recorded synchronously.

5. Atmospheric Profile Generation Algorithm Functional Design

The Atmospheric Profile Generation Algorithm is composed of many individual algorithms that are linked together to generate the final results. Presented in the following sections are these individual algorithms. Diagrams show the required input variables and output variables from the calculations. The overall system is presented in Figure 3. Definitions of all variables presented can be found in Appendix A

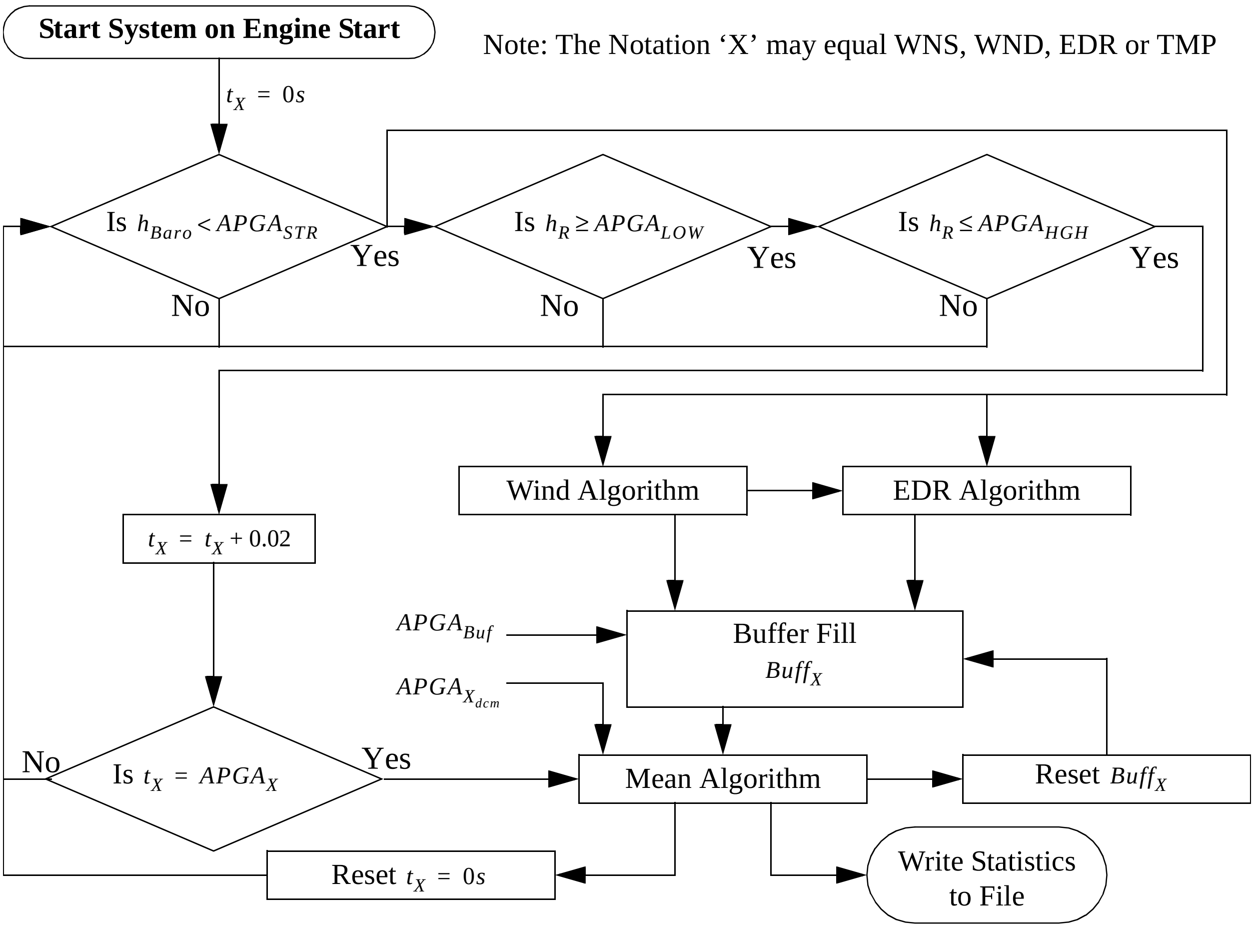

Figure 3: Algorithm System Flowchart

5.1 Inertial Wind Recovery Algorithm

The Inertial Wind Recovery Algorithm estimates a three-component wind vector and high bandwidth turbulence gusts for use in the Atmospheric Profile Generation Algorithm. The purpose of this algorithm is to derive quality wind measurements, which are not currently available on commercial aircraft, from data available on an aircraft's recording system. The inertial wind vector is derived from measured aircraft parameters as shown in Figure 4 and subsequent equations. The derivation is non-aircraft specific in its estimation of the wind vector $(\overrightarrow{W_E})$. The inertial vertical wind component (W_{Z_E}) is used as an input to the eddy dissipation rate algorithm [5 and 6].

5.1.1 *Algorithm Diagram*

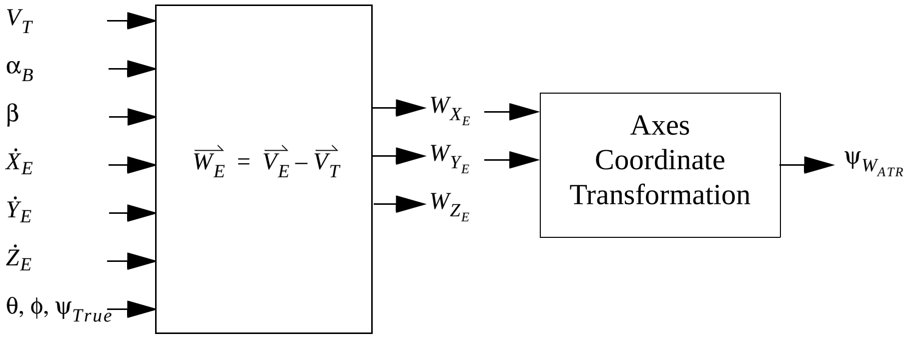

Figure 4: Inertial Wind Recovery Algorithm

5.1.2 *Algorithm Equations*

$$\begin{aligned} V_{A_X} = {} & V_T(\cos\alpha_B\cos\beta\cos\theta\cos\psi + \sin\beta\sin\phi\sin\theta\cos\psi - \sin\beta\cos\phi\sin\psi \\ & + \sin\alpha_B\cos\beta\cos\phi\sin\theta\cos\psi + \sin\alpha_B\cos\beta\sin\phi\sin\psi) \end{aligned} \tag{5-1}$$

$$\begin{aligned} V_{A_Y} = {} & V_T(\cos\alpha_B\cos\beta\cos\theta\sin\psi + \sin\beta\sin\phi\sin\theta\sin\psi + \sin\beta\cos\phi\cos\psi \\ & + \sin\alpha_B\cos\beta\cos\phi\sin\theta\sin\psi - \sin\alpha_B\cos\beta\sin\phi\cos\psi) \end{aligned} \tag{5-2}$$

$$V_{A_Z} = V_T(-\cos\alpha_B\cos\beta\sin\theta + \sin\beta\sin\phi\cos\theta + \sin\alpha_B\cos\beta\cos\phi\cos\theta) \tag{5-3}$$

$$W_{X_E} = \dot{X}_E - V_{A_X} \tag{5-4}$$

$$W_{Y_E} = \dot{Y}_E - V_{A_Y} \tag{5-5}$$

$$W_{Z_E} = \dot{Z}_E - V_{A_Z} \tag{5-6}$$

Wind Direction, $\psi_{W_{ATR}}$ [$0°$ is wind from True North]

For $W_{X_E} > 0.0$

$$\psi_{W_{ATR}} = \operatorname{atan}\left(\frac{W_{Y_E}}{W_{X_E}}\right) \cdot \frac{180}{\pi} - 180° \tag{5-7}$$

For $W_{X_E} < 0.0$ and $W_{Y_E} > 0.0$

$$\psi_{W_{ATR}} = \operatorname{atan}\left(\frac{W_{Y_E}}{W_{X_E}}\right) \cdot \frac{180}{\pi} \tag{5-8}$$

For $W_{X_E} < 0.0$ and $W_{Y_E} < 0.0$

$$\psi_{W_{ATR}} = \operatorname{atan}\left(\frac{W_{Y_E}}{W_{X_E}}\right) \cdot \frac{180}{\pi} - 360° \tag{5-9}$$

For $W_{X_E} = 0.0$ and $W_{Y_E} > 0.0$

$$\psi_{W_{ATR}} = -90° \tag{5-10}$$

For $W_{X_E} = 0.0$ and $W_{Y_E} < 0.0$

$$\psi_{W_{ATR}} = -270° \tag{5-11}$$

For $W_{X_E} = 0.0$ and $W_{Y_E} = 0.0$

$$\psi_{W_{ATR}} = -90° \tag{5-12}$$

5.2 Wind Speed Calculation

Horizontal wind speed is an output of the Atmospheric Profile Generation Algorithm. The horizontal wind speed can be calculated from the sum of the squares of the horizontal inertial vector of the derived winds. Comparisons have been made between this calculation and the recorded IRU Wind Speed variable on the NASA B757-200 with favorable results. It has been noted in past WxAP flight tests that the IRU Wind Speed is susceptible to aircraft maneuver influence; whereas, the formulation of the derived winds presented takes aircraft maneuvering into account.

5.2.1 Algorithm Diagram

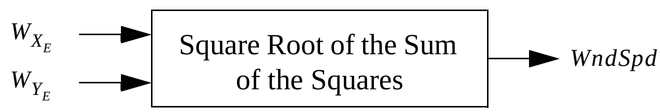

Figure 5: Wind Speed Calculation

5.2.2 Algorithm Equation

$$WndSpd = \sqrt{W_{X_E}^2 + W_{Y_E}^2} \tag{5-13}$$

5.3 Winds-Based Eddy Dissipation Rate Algorithm

The Winds-Based Eddy Dissipation Rate Algorithm provides a measurement of EDR based on the measured inertial vertical wind and removes the airplane response from the estimate of eddy dissipation rate.[5] Inputs to the algorithm are the recovered inertial vertical wind gust (W_{Z_E}) and the aircraft true airspeed (V_T) as shown in Figure 6. True Airspeed is filtered with a low pass filter to smooth possible noisy signals from the ship system. The inertial vertical wind is filtered using a digital bandpass filter and passed into a running standard deviation (sigma) calculation. The running sigma of the filtered inertial vertical winds is then combined as depicted in the diagram below with a finite integral of Kolmogorov turbulence. This integral is dependent on the algorithm’s cut-off frequencies and is also calculated at each time step due to the dependence on true airspeed. The cut-off frequencies, developed in Reference [7], preserve the inertial sub-range of the wind field; however, they are ‘tuned’ to cruise flight conditions. The cut-off frequencies may require adjustment for low altitude and low speed conditions of the aircraft (see Section 8 and 9). Additional Information on the theoretical development of Equation (5-14) may be found in Reference [8].

5.3.1 Algorithm Diagram

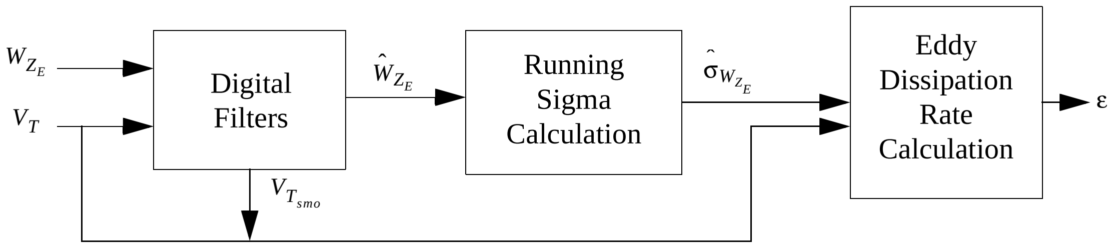

Figure 6: Winds Based Eddy Dissipation Rate Algorithm

5.3.2 Algorithm Equations

$$\varepsilon = \left[\frac{\hat{\sigma}_{W_{Z_E}}}{\sqrt{0.7 \cdot V_{T_{smo}}^{2/3} \int_{\omega_L}^{\omega_U} \omega^{\frac{-5}{3}} \, d\omega}} \right]^3 \tag{5-14}$$

where:

$$\int_{\omega_L}^{\omega_U} \omega^{\frac{-5}{3}} \, d\omega = \frac{3}{2} \cdot \left(\omega_L^{-\frac{2}{3}} - \omega_U^{-\frac{2}{3}} \right) \tag{5-15}$$

5.4 Statistic Calculation

The statistic calculation used in the Atmospheric Profile Generation Algorithm is a mean calculation based on a given input. The algorithm has been designed to collect values of a group of parameters into individual buffers. When the buffers have been filled to the desired window a mean calculation is performed on either Wind Speed, Wind Direction, EDR, or Static Temperature. A median value is determined for each of the positional parameters ($Time$, h_R, Lon_{IRU} and Lat_{IRU}). The resultant individual mean and median values are then stored for output and the buffers are reset in order to begin the statistic process again. The buffering of the data may use a fixed length, consecutive window or a fixed length, sliding window determined by setting $APGA_{BUF}$ in the algorithm's configuration file. For a consecutive window, after the reset of the buffer, the next buffer block starts at the end of the previous block. A sliding window is of fixed length with its contents changing at each time step. The oldest value is dropped and the current value at time t is added. If $APGA_{BUF}$ is set to zero (consecutive statistic window), decimator values are ignored in the data processing.

5.4.1 Algorithm Diagram

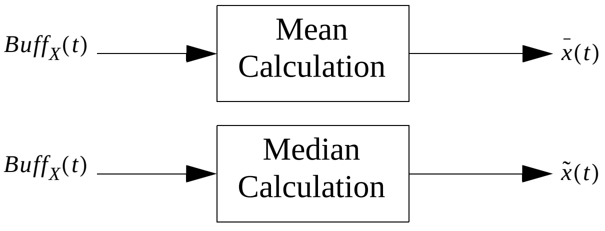

Figure 7: Statistic Calculation - Mean and Median

5.4.2 Algorithm Equation

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} Buff_{X_i} \tag{5-16}$$

$$\tilde{x} = Buff_X\left(\frac{n+1}{2}\right) \tag{5-17}$$

6. Input Requirements

The Atmospheric Profile Generation Algorithm requires a time history of seventeen parameters in order to be executed. The format of the input file requires a comma delimited ASCII text file that must be consistent from case to case when it comes to the order of the parameters due to the structure of the algorithm. The algorithm can sufficiently determine the length of a particular data set when an input file is read into memory. As part of the final deliverable for Task 1, an input file has been provided for each of the twenty-seven runs used in the development of the Algorithm. Each file is named for the associated flight number and the sequence of the approach / departure run at DFW. Table 3 lists the parameters required in the input file and the order of the columns.

Table 3: APGA Input Parameters and Column Order

Parameter	Units	Column	Parameter	Units	Column	Parameter	Units	Column
$Time$	s	1	ϕ	deg	7	Lon_{IRU}	deg	13
h_{Baro}	ft	2	θ	deg	8	ψ_{trk}	deg	14
h_R	ft	3	ψ	deg	9	$\dot{X}_E$	kts	15
V_{GS}	kts	4	$Temp$	deg C	10	$\dot{Y}_E$	kts	16
α_B	deg	5	V_T	kts	11	$\dot{Z}_E$	ft/min	17
β	deg	6	Lat_{IRU}	deg	12			

A detailed listing of the algorithm's required parameters and the resulting output variables is provided in Appendix A.

6.1 Simulation Configuration File Format

A configuration and control file has been created to be used with the Atmospheric Profile Generation Algorithm simulation. An aircraft implementation would not require a configuration file because the algorithm constants would be fixed. The purpose of the configuration file is to quickly and easily access and change the constants to be used with the algorithm simulation. Written as an ASCII text file, the configuration file must be named *APGA - Config.txt*. The file follows the following format, where the symbol names are the same as those described throughout this document.

$APGA_{STR}$, $APGA_{LOW}$, $APGA_{HGH}$
$APGA_{BUF}$
$APGA_{WNS}$, $APGA_{WND}$, $APGA_{EDR}$, $APGA_{TMP}$
$APGA_{WNSdcm}$, $APGA_{WNDdcm}$, $APGA_{EDRdcm}$, $APGA_{TMPdcm}$

6.1.1 Example Configuration File

3000.,30.,600.
1
5,5,5,20
100,100,100,100

6.2 Output File Format

For each of the parameters of interest (Wind Speed, Wind Direction, EDR or Static Temperature), an individual but similarly formatted output file is produced for a set of processed data. The following paragraphs provide details on each part of the common output file.

6.2.1 Header Format

The header format of each individual parameter's file will have the following form.

filename
upper_bound, lower_bound, averaging_period, decimator, buffer
data_lines

- **filename** indicates the associated run name and the parameter of interest for the generated data.
- **upper_bound** is the upper bound height in meters of the region of interest used by the Algorithm.
- **lower_bound** is the lower bound height in meters of the region of interest used by the Algorithm.
- **averaging_period** is the size in seconds of the statistics window used for the respective parameter by the Algorithm.
- **decimator** is the value used to down sample the original data stream from the Algorithm.
- **buffer** refers to the type of statistics window used in the Algorithm. A value of 0 represents a fixed length, consecutive window and a value of 1 represents a fixed length, sliding window for the statistics.
- **data_lines** indicates that one line of data has been generated for an individual altitude point

6.2.2 Data Format

Following the header section of the output file is a line of data for a parameter (Wind Speed, Wind Direction, EDR or Static Temperature) at each altitude data point. The data is comma delimited with a comma at the end of each successive line. Data is written to the file in fixed width format. Extra white space is ignored. Each data line contains the following fields:

- **MDN_TIME** is the median value of Time (seconds from midnight) for the averaging period of the statistic window.
- **MDN_DIST** is the median value of distance along the aircraft track from the start the data file for the averaging period of the statistic window.
- **MDN_ALT** is the median value of aircraft above ground level in feet for the averaging period of the statistic window.
- **MDN_LON** is the median value of the aircraft's longitudinal position in decimal degrees for the averaging period of the statistic window.
- **MDN_LAT** is the median value of the aircraft's latitudinal position in decimal degrees for the averaging period of the statistic window.
- **AVERAGE** is the average value of the parameter of interest for the averaging period of the statistic window. The unit of wind speed is meters per second; wind direction is decimal degrees referenced from true north; eddy dissipation rate is meters squared per second cubed; and static temperature is degrees centigrade.

6.2.3 Vertical Resolution

The data presented in the output file will cover a range of altitude in feet between the upper and lower boundary values specified in the Atmospheric Profile Generation Algorithm. For testing purposes in Task 1, this altitude region is 1,870ft (570m). The vertical resolution of the output data is controlled by the value of the decimator constant, for each parameter of interest, defined in the configuration file. If the decimator is set to 1, every calculated statistic point is reported creating a vertical resolution dependent on the sample rate of the original aircraft data file. For the Task 1 data analysis, the sample rate was 50 Hz. This creates a possible vertical resolution of 0.2 feet per sample for a decimator value of 1. If the decimator is set to a value of 100, as used in the results analysis for Task 1, every 100th point is captured in the data file yielding a possible altitude resolution of 20 feet per data line.

6.2.4 Filename Format

For the Atmospheric Profile Generation Algorithm, each output file will have the following filename format: runname-*profile*_parameter.*csv* Text presented in *italics* is used to identify the file type and its general contents.

- **runname** refers to the run name of the associated input aircraft data file. Runname is limited to ten characters and is shortened is fewer are provided.
- **parameter** refer to an abbreviation of any one of the parameters of interest. **WNS** is used for Wind Speed, **WND** is used for Wind Direction, **EDR** is used for Eddy Dissipation Rate and **TMP** is used for Static Temperature.

6.2.5 Example File

The following listing is a small portion of a larger output file from the Atmospheric Profile Generation Algorithm for the parameter Wind Speed.

```
R162-RUN01-PROFILE_WNS.CSV
600.00, 30.00, 5., 100, 1.,
22251.91000, 51207.57000, 1935.50000, -97.02595, 32.97512, 16.48736,
22253.91000, 51320.69000, 1908.50000, -97.02595, 32.97409, 16.43858,
22255.91000, 51433.55000, 1882.87500, -97.02595, 32.97306, 16.39669,
22257.91000, 51546.05000, 1840.75000, -97.02595, 32.97203, 16.43334,
22259.91000, 51658.55000, 1840.50000, -97.02595, 32.97100, 16.45041,
22261.91000, 51771.05000, 1806.37500, -97.02612, 32.96997, 16.39615,
22263.91000, 51883.55000, 1753.12500, -97.02612, 32.96894, 16.36082,
```

For the example presented, the upper bound of the algorithm simulation is 600m. The lower bound is 30m. A statistics window of 5 seconds is set. The decimator for the Wind Speed parameter is chosen to be 100 (every 100th calculated value is written to file) and a sliding statistics window is designated by the value of 1. Remaining lines of information are the resulting data from the simulation with the columns presented in the following order: Median Time, Median Distance, Median Radio Altitude, Median Longitude, Median Latitude and the Mean value of Wind Speed.

7. Testing and Verification of the Algorithm

The Atmospheric Profile Generation Algorithm required extensive testing throughout its development. Intermediate results were constantly verified for sensibility and comparison to previously recorded research ship values. This type of testing has produced a robust algorithm for processing flight data from the NASA B757-200 research aircraft. To test the algorithm and its components, thirteen runs from flight R162 and fourteen runs from flight R165 were used (see Table 2). The following paragraphs and figures present the results of key runs and explain their significance in the verification and development of the algorithm for the WakeVAS program. Remaining individual runs and summary plots are located in Appendix B.

7.1 Explanation of Figures

In the figures, the data and results from full NASA B757-200 research system are represented as solid diamonds. For each run, two position figures (plan and profile view) were created to show where along the aircraft's track statistical points were created. From the positional data and the corresponding figures the operation of the algorithm's trigger logic and statistical collection subroutines can be verified. Presented in Figure 8 is a representative track of the B757-200 along an approach into the DFW airport. The aircraft track in radio altitude is presented in the lighter, gray line passing through the statistical points in the second half of the figure.

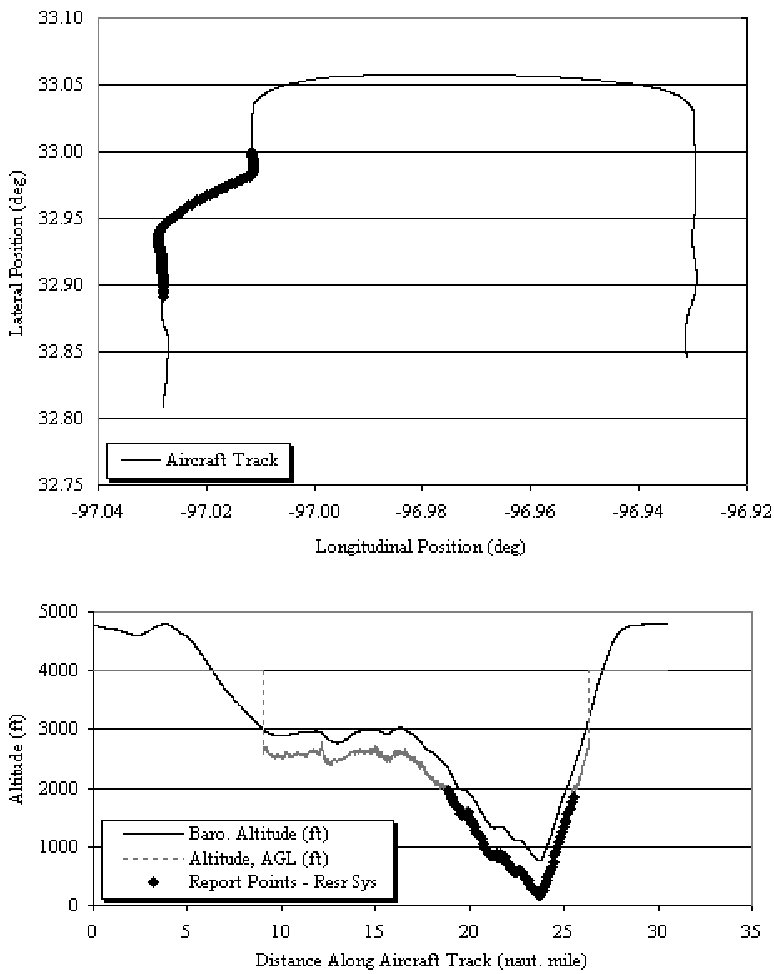

Figure 8: Representative Positional Information Display for R162-Run 09

Figure 9 presents the data for the four meteorological parameters of interest (Wind Speed & Direction, EDR and Static Temperature) produced by the algorithm. The ordinate for each chart represents the aircraft height (AGL) in feet and the abscissa represents each measured parameter with its units specified. The number of points typically collected for a run can exceed 10,000 plus points for a sliding window with research quality data, but information presented in Figure 9 uses a decimator to reduce the total number of output points, providing a more manageable product. Future WakeVAS implementations may use these data points in the estimation of the final product for the program.

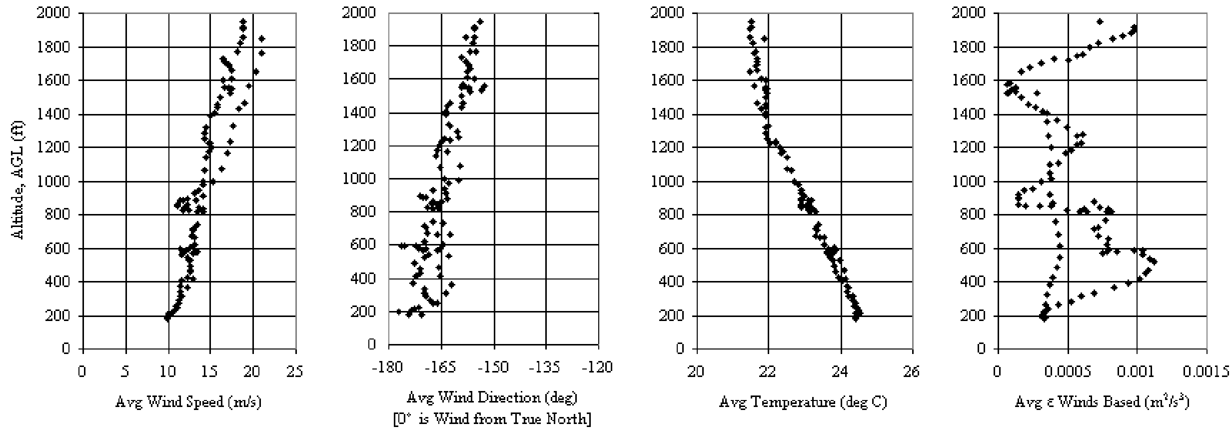

Figure 9: Representative Statistical Results from the Algorithm for R162-Run 09

For some of the plots presented in Appendix B, a display issue in the graphs appears when reviewing the results contained in the statistics for wind direction. The plot's abscissa is set for a maximum range of -180 to 180 degrees. A crossover at ± 180 degrees occurs as the wind rotates around a southerly direction. Figure 10 illustrates this issue. The crossover gives the illusion that there is almost a 360 degree difference between data points; however, accounting for the crossover, the wrapping of the information around the ± 180 degree mark is nearly seamless.

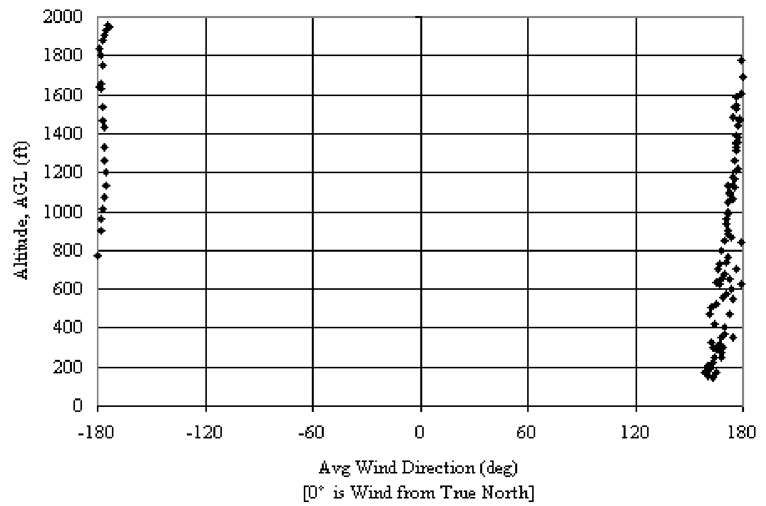

Figure 10: ± 180 **degree Crossover for R162-Run 01**

7.2 Analysis and Results

A total of 27 runs were used in the verification and analysis of the Atmospheric Profile Generation Algorithm. A plot has been created for each individual run to graphically illustrate the profiles for the parameters of interest and the accompanying positional information. Figure 11 presents a summary of the results from R162-Run09. Wind Speed, Wind Direction and Static Temperature each illustrate a possible simple curvilinear fit to the data points. Data collected at both the beginning and end of the runway correlate well together leading to the conclusion that spatial position variation of the collected data is small in comparison to the magnitude of the collected data points. Collected EDR points tend to be sparsely populated over a range of values, but it should be noted that the magnitude of EDR is extremely small in comparison to significant values ($\varepsilon = 0.12\ m^2/s^3$) required to create intense turbulence effects on aircraft. Also, the points are more spread out when compared with the other meteorological parameters. This is caused by the use of the decimator and the fast change in EDR at such small scaled values.

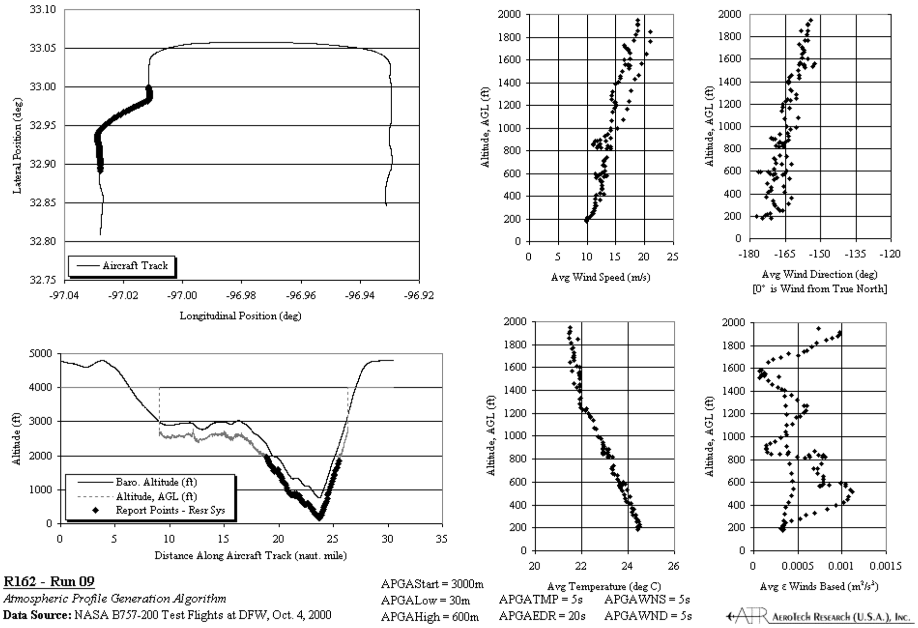

Figure 11: Representative Single Run Summary for R162-Run09

Figure 12 represents similar information for R165-Run05. Like Figure 11, the data correlates well for Wind Speed & Direction and Static Temperature. Eddy Dissipation Rate for the this particular run is near zero. This happens to be the case for all of the runs for flight R165 with only minor deviations from the ordinate axis. It is assumed that the ambient winds were calm on this flight day yielding little turbulence in the region of the DFW runway.

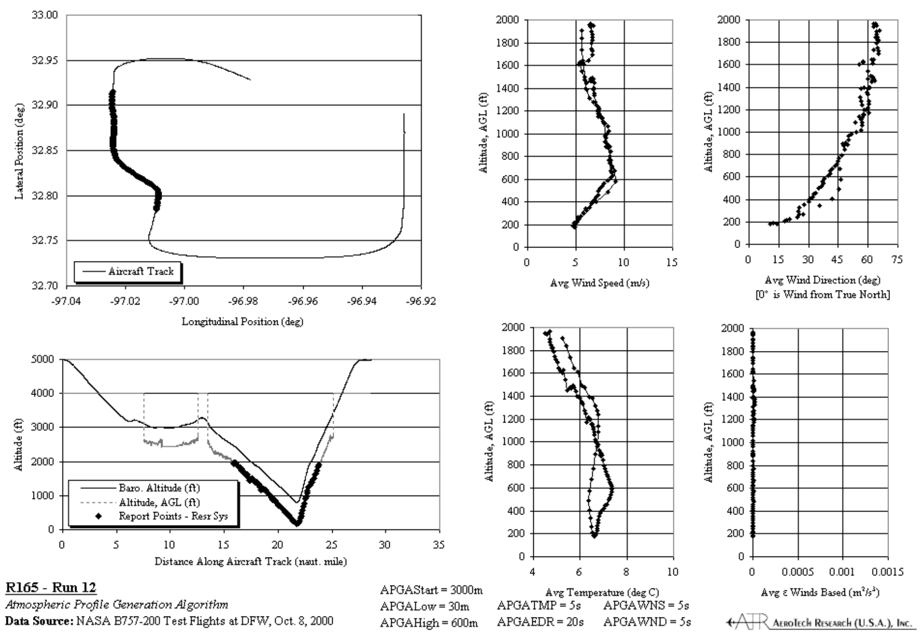

Figure 12: Representative Single Run Summary for R165-Run12

It is NASA's intention to build profiles based on 30 minutes of collected aircraft data for use in WakeVAS. A thirty minute profile for one runway could include six to seven aircraft either on approach or departure, depending on spacing. For the flight test data sets, two runs were consistently made within a thirty minute period. Figure 13 and Figure 14 are a composite of two runs from flight R162 and R165 respectively that spans thirty minutes of flight time. For each of the two included runs, the data fits well for the parameters of interest. The fit with Eddy Dissipation Rate is considered good because of the small scale of the numbers. Similar thirty minute block windows for flight R162 and R165 are presented in Appendix B.

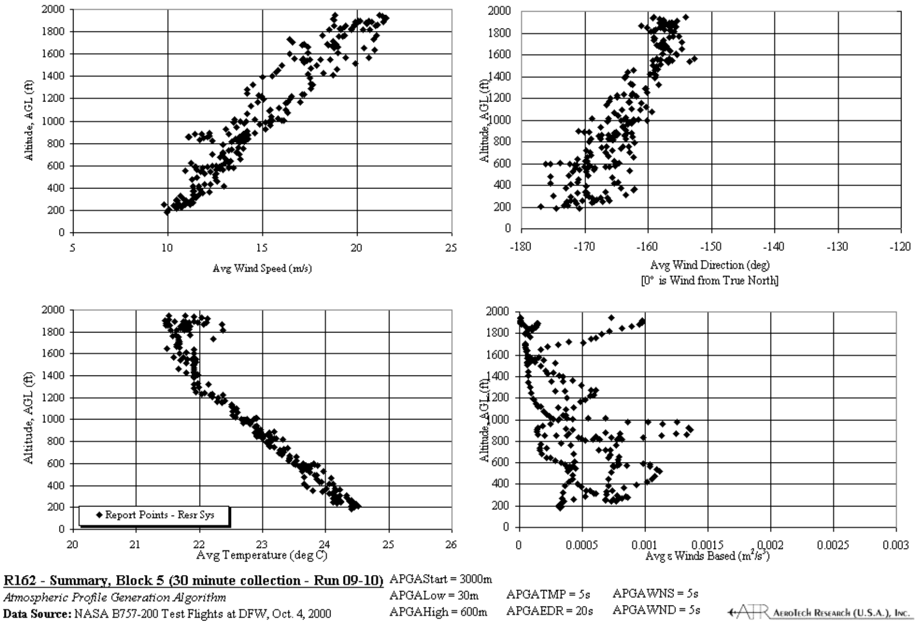

Figure 13: Thirty Minute Block for Flight R162

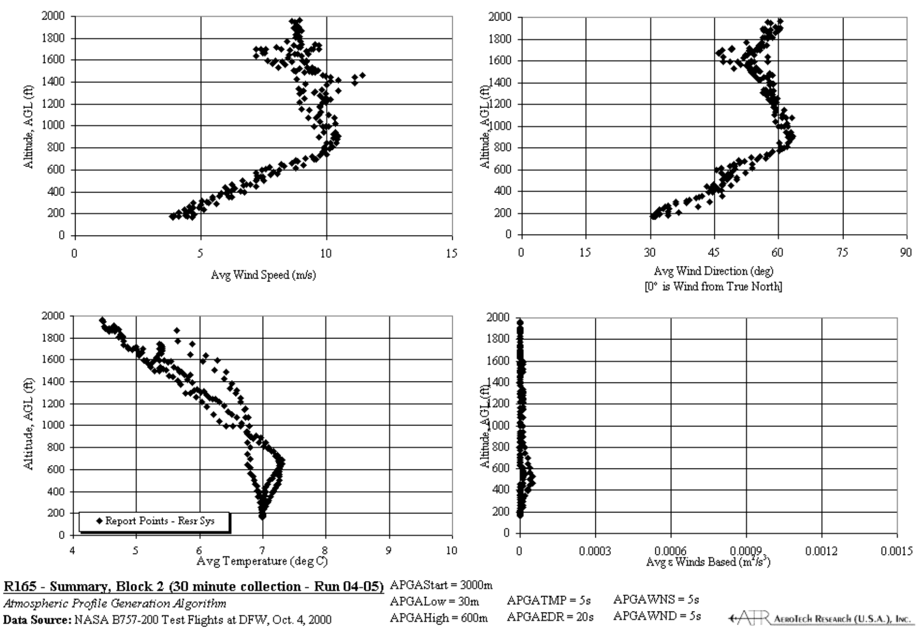

Figure 14: Thirty Minute Block for Flight R165

For each of the plots presented, the results of the Atmospheric Profile Generation Algorithm appear consistent with known meteorological patterns for open airspaces. Initial comparisons with general ground data collected at DFW indicate a confidence in the results presented.

8. Measures of Known Error

Measurements on the NASA B757-200 are sampled at high frequency (up to 100 Hz) and are made from calibrated sensors. AeroTech's previous experience with the NASA B757-200 data provides confidence in the consistency and reasonability of the data measured aboard the aircraft. However, without additional data from external sources for corroboration, there is no capability to fully assess the measurement errors in the NASA B757-200 data. The best proof for accuracy in the resulting data profiles in this work is to look for consistency within the results, as exhibited by the thirty minute profile plots for the two flight days presented.

There is no known inherent error in the Atmospheric Profile Generation Algorithm for Static Temperature, Wind Speed and Wind Direction. An area that needs further evaluation is the cut-off frequencies used in the EDR calculation of the Algorithm. Tuned for cruise flight conditions, the frequencies used should be further tested for feasibility and correctness at low altitude configurations. The best way to assess the error is to have a truth, for comparative analysis, from other measurement sources independent of the aircraft.

9. Future Work

Initial results illustrate that quality meteorological data can be gathered using the NASA B757-200 research aircraft system through standard airfield approach conditions. Viable data can be collected on departure that correlates well with approach data given the current values of the constants in the algorithm. If data is downlinked from several aircraft equipped with the Algorithm, a consistent thirty minute summary chart can be created for each of the parameters of interest.

Current Algorithm implementation and simulation uses either a fixed length, consecutive or sliding statistics window. Further work is suggested in the optimization of the values of the individual parameter's statistic window size.

Additional work should include the refinement of the cut-off frequencies for the eddy dissipation rate calculation. The current values were developed for the TPAWS program for standard turbulence penetration speed in cruise with a clean configuration. The cut-off frequencies may be affected in this WakeVAS work due to the low airspeed and changing configuration (gear and flap positions) of the aircraft.

The current form of the Atmospheric Profile Generation Algorithm is tuned to the research data available from the NASA B757-200. The next step is to expand the Algorithm in testing and implementation with commercial ship system types. A commercial ship will require additional preprocessing of the data sources to put it into a compatible form with the Algorithm. In addition, it cannot be assumed that track angle will always be available. Much of this work may be done in Task 2 if commercial aircraft data is made available.

Further work should also include refinement in the estimation of sideslip. Sideslip is generally not available from commercial aircraft systems. In cruise flight, sideslip is not a major player in the horizontal winds, but as the aircraft is approaching a runway, the magnitude of sideslip may increase dramatically given environmental conditions. Crosswinds at the airfield are an important part in the assessment of air mass motion across the runway.

10. References

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8. Cornman, L., Morse, C., and Cunning, G., “Real-Time Estimation of Atmospheric Turbulence Severity from In Situ Aircraft Measurements,” Journal of Aircraft, Vol. 32, No. 1, January - February 1995.

Appendix A

Atmospheric Profile Generation Algorithm Symbology

Table A.1: APGA Symbology

Variable	Description	Units	Positive Sense	Associated Algorithm
$APGA_{Buf}$	Statistics Buffer Type: 0 - Consecutive, 1 - Sliding	unitless	always	Statistics
$APGA_{EDR}$	Sliding Window Size of Eddy Dissipation Rate Statistics Buffer	sec	always	System Trigger
$APGA_{EDRdcm}$	EDR Statistics Buffer Decimator	unitless	always	Statistics
$APGA_{HGH}$	Upper Bound of Operation of the Algorithm	m	always	System Trigger
$APGA_{LOW}$	Lower Bound of Operation of the Algorithm	m	always	System Trigger
$APGA_{STR}$	Altitude (AGL) to begin processing algorithms	m	always	System Trigger
$APGA_{TMP}$	Sliding Window Size of Static Temperature Statistics Buffer	sec	always	System Trigger
$APGA_{TMPdcm}$	Static Temperature Statistics Buffer Decimator	unitless	always	Statistics
$APGA_{WND}$	Sliding Window Size of Wind Direction Statistics Buffer	sec	always	System Trigger
$APGA_{WNDdcm}$	Wind Direction Statistics Buffer Decimator	unitless	always	Statistics
$APGA_{WNS}$	Sliding Window Size of Wind Speed Statistics Buffer	sec	always	System Trigger
$APGA_{WNSdcm}$	Wind Speed Statistics Buffer Decimator	unitless	always	Statistics
$Buff_X$	Parameter ‘X’ Buffer	input dependent	input dependent	Statistics
h_{Baro}	Altitude, Barometric	ft	always	System Trigger, Statistics

Table A.1: APGA Symbology

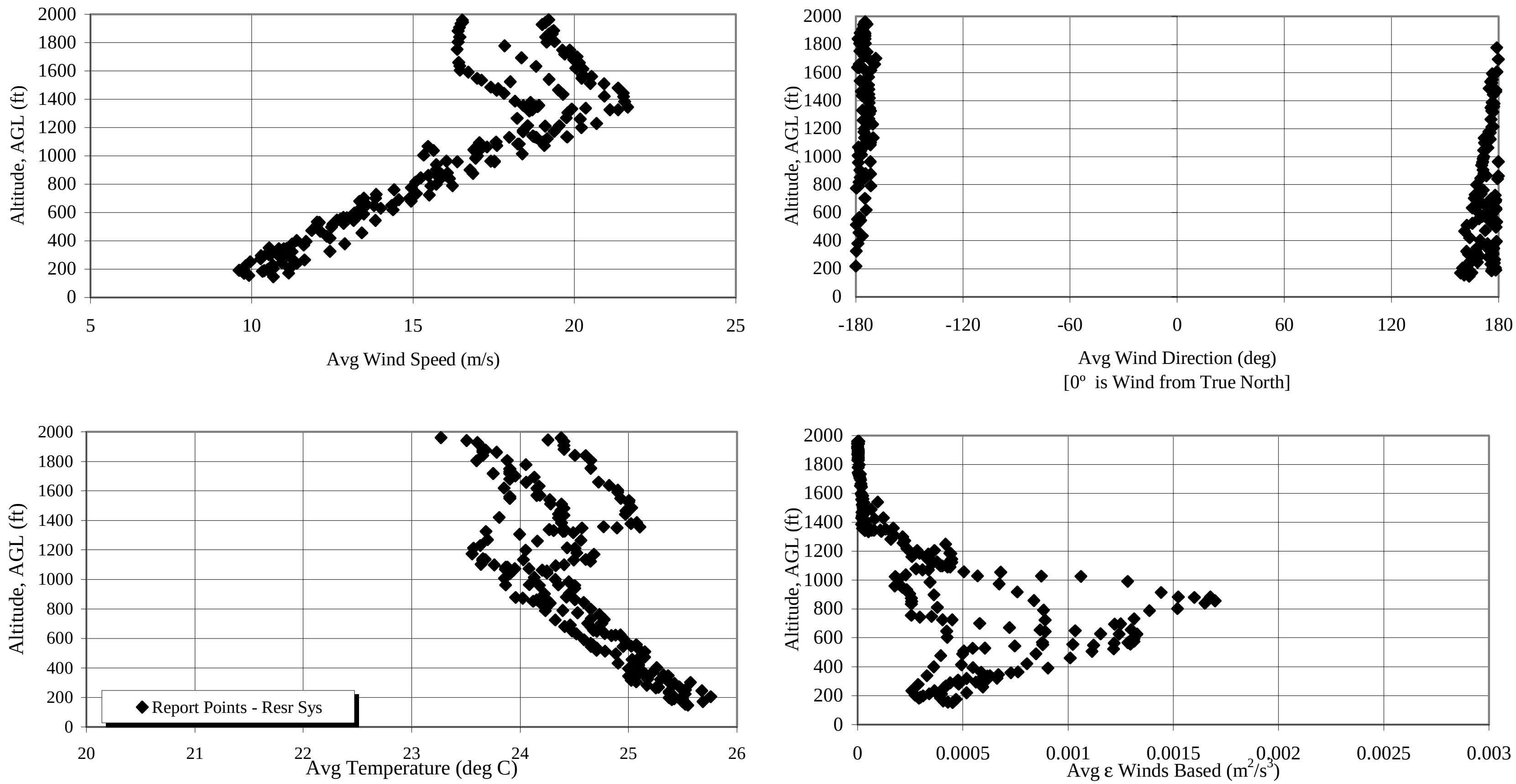
Variable	Description	Units	Positive Sense	Associated Algorithm
h_R	Altitude AGL, Radio	ft	always	System Trigger, Statistics
Lat_{IRU}	Latitude Position	deg	north from 0 deg	Statistics
Lon_{IRU}	Longitude Position	deg	east from 0 deg	Statistics
$Temp$	Temperature, Static	deg C	above freezing	Statistics
$Time$	Time of Data Series	s	always	Statistics
t_X	Statistics Windowing Period for Parameter 'X'	s	always	System Trigger
V_{GS}	Groundspeed	kts	always	Wind Speed Calc
V_T	True Airspeed	kts	always	Wind Recovery, Wind EDR
$V_{T_{smo}}$	True Airspeed, smoothed	m/s	always	Wind EDR
$WndSpd$	Inertial Wind Speed, Derived	m/s	always	Wind Speed Calc, Statistics
W_{X_E}	Wind Component in the Inertial Frame in *x*-direction	m/s	positive northward	Wind Recovery, Wind Speed Calc
W_{Y_E}	Wind Component in the Inertial Frame in *y*-direction	m/s	positive eastward	Wind Recovery, Wind Speed Calc
W_{Z_E}	Wind Component in the Inertial Frame in *z*-direction	m/s	positive downward	Wind Recovery, Wind EDR
$\hat{W}_{Z_E}$	Filtered Inertial Vertical Wind	m/s	down	Wind EDR
x	Input Time Series to be Averaged	input dependent	input dependent	Statistics
$\bar{x}$	Averaged Time Series	input dependent	input dependent	Statistics
$\dot{X}_E$	Inertial x Velocity	m/s	north	Wind Recovery
$\dot{Y}_E$	Inertial y Velocity	m/s	east	Wind Recovery
$\dot{Z}_E$	Inertial z Velocity	m/s	down	Wind Recovery

Table A.1: APGA Symbology

Variable	Description	Units	Positive Sense	Associated Algorithm
α_B	Angle of Attack, Body	deg	trailing edge up	Wind Recovery
β	Sideslip	deg	trailing edge left	Wind Recovery
Δt	Time Step of Algorithm	s	always	Wind EDR
ε	Eddy Dissipation Rate	m^2/s^3	always	Wind EDR, Statistics
θ	Pitch Angle	deg	up	Wind Recovery
$\hat{\sigma}_{W_{Z_E}}$	Filtered RMS of Inertial Vertical Wind	m/s	down	Wind EDR
ϕ	Roll Angle	deg	right wing down	Wind Recovery
ψ_{trk}	Track Angle	deg	CW from north	Wind Recovery
ψ_{true}	Heading, True	deg	CW from north	Wind Recovery
$\psi_{W_{ATR}}$	Wind Direction, Derived	deg	CW from north	Wind Recovery, Statistics
ω_L	Filter Cut-off Frequency, Higher	rad/s	greater than 0	Wind EDR
ω_U	Filter Cut-off Frequency, Lower	rad/s	greater than 0	Wind EDR

Appendix B

Atmospheric Profile Generation Algorithm Test Data Results



R162 - Summary, Block 1 (30 minute collection - Run 01-02)

Atmospheric Profile Generation Algorithm

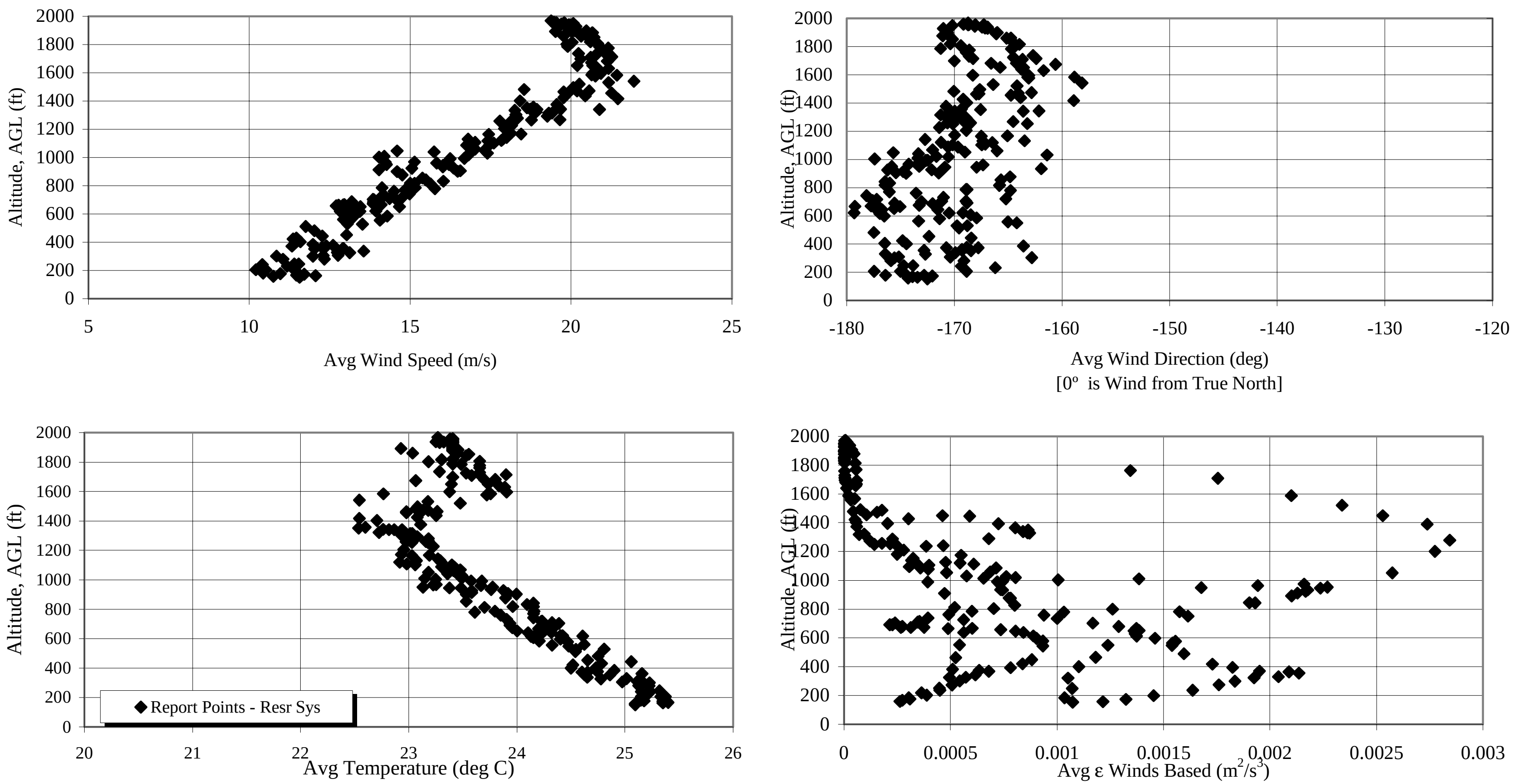
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



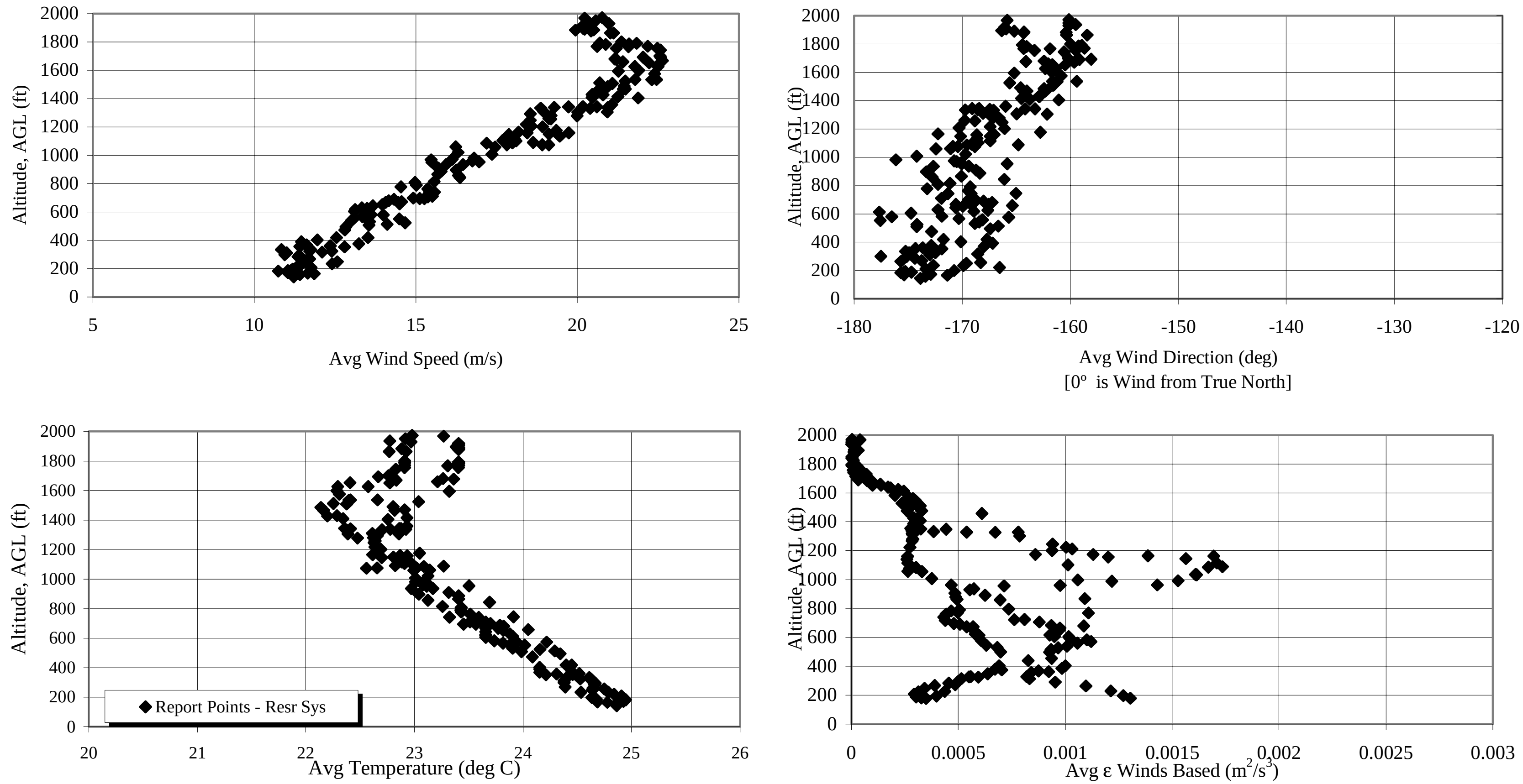
<u>R162 - Summary, Block 2 (30 minute collection - Run 03-04)</u>
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



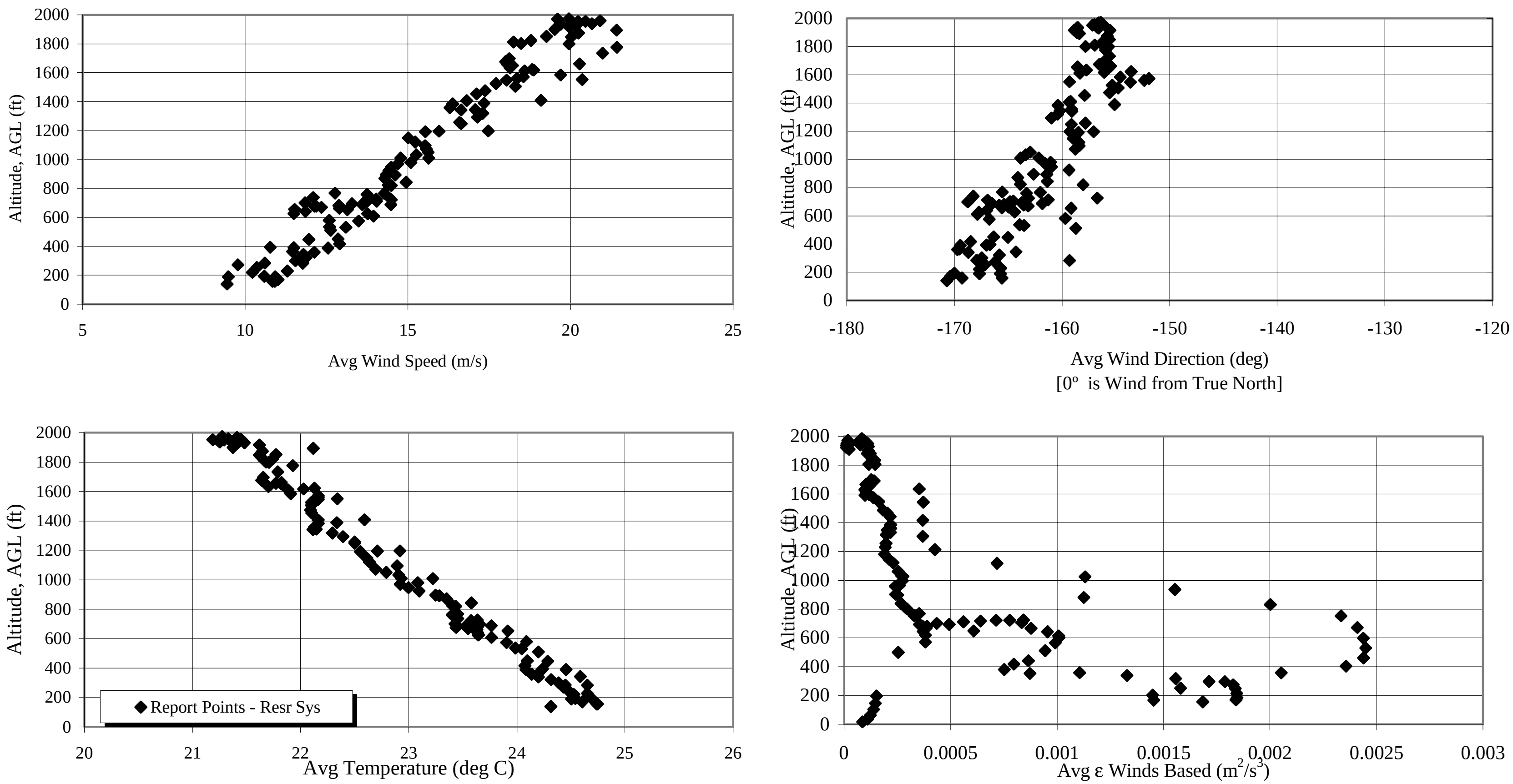
R162 - Summary, Block 3 (30 minute collection - Run 05-06)
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



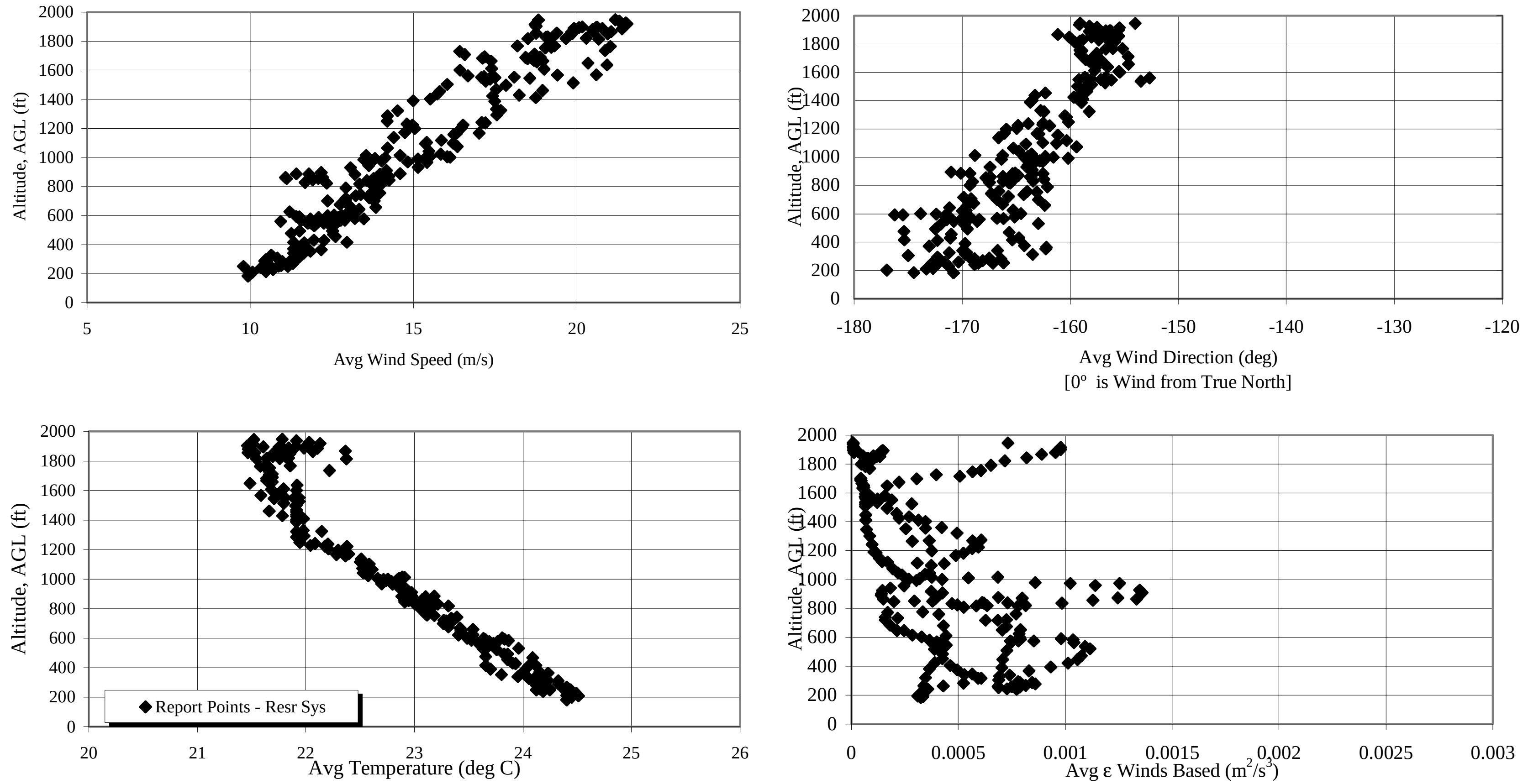
R162 - Summary, Block 4 (30 minute collection - Run 07-08)
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



R162 - Summary, Block 5 (30 minute collection - Run 09-10)

Atmospheric Profile Generation Algorithm

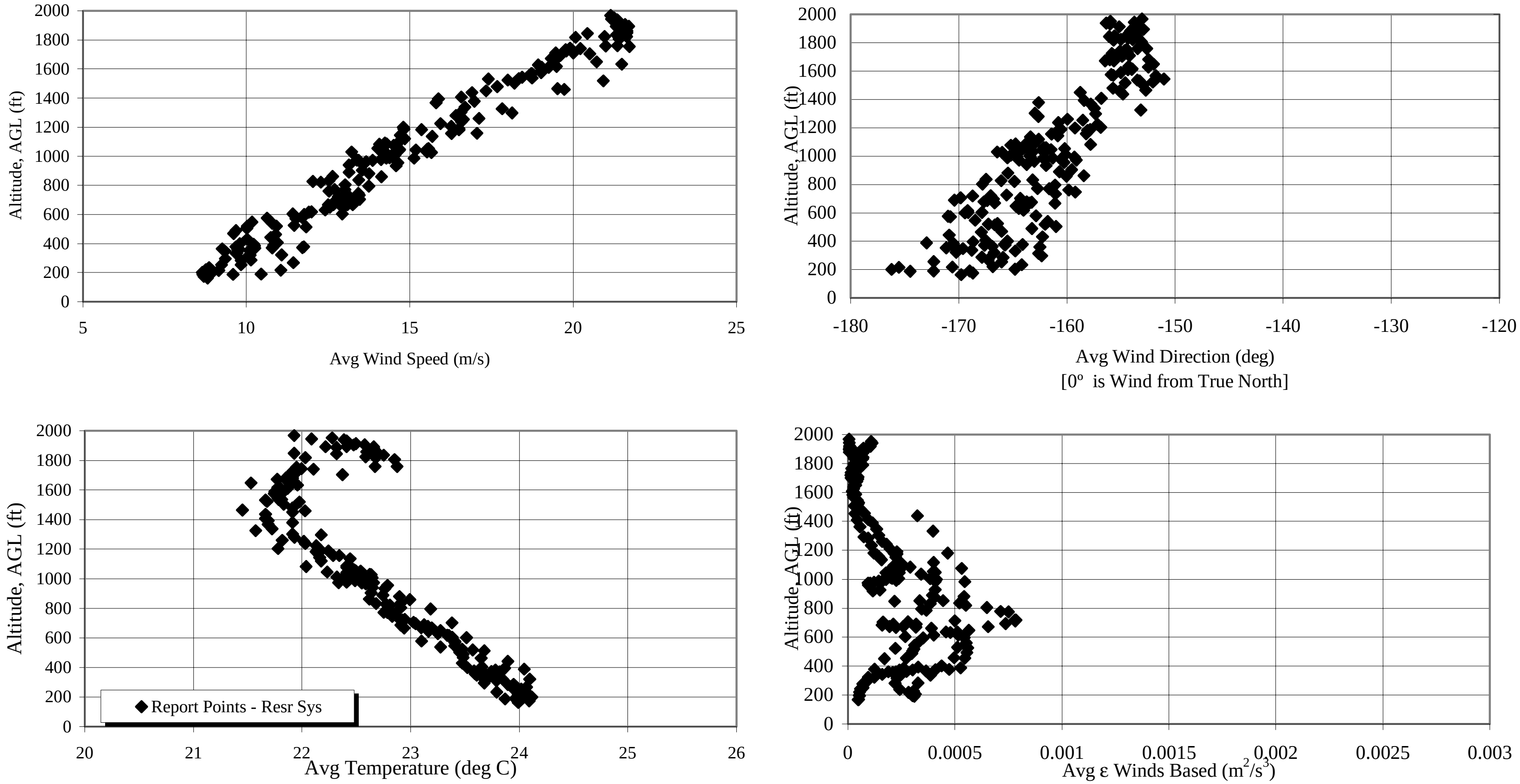
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



<u>R162 - Summary, Block 6 (30 minute collection - Run 11-12)</u>

Atmospheric Profile Generation Algorithm

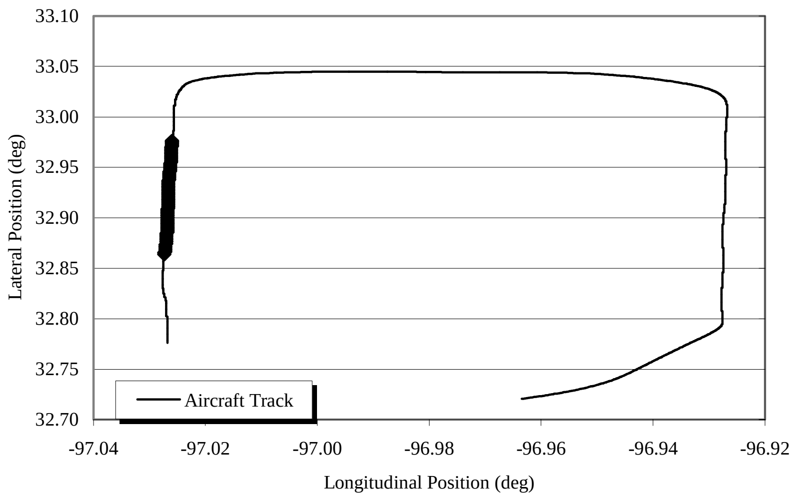
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

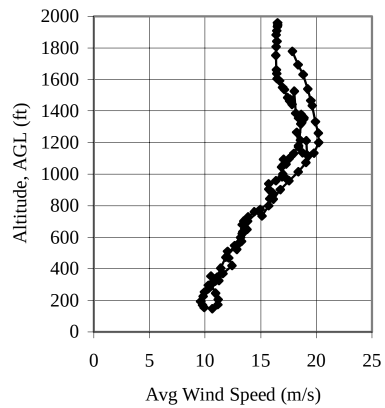
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

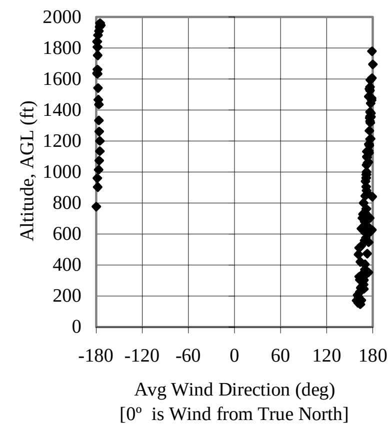
APGATMP = 5s
APGAEDR = 20s

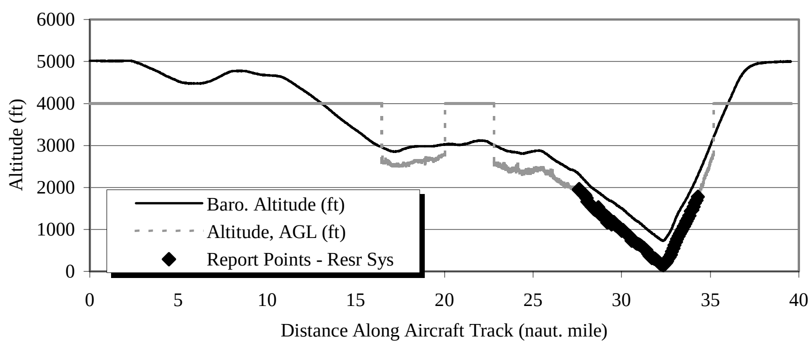
APGAWNS = 5s
APGAWND = 5s

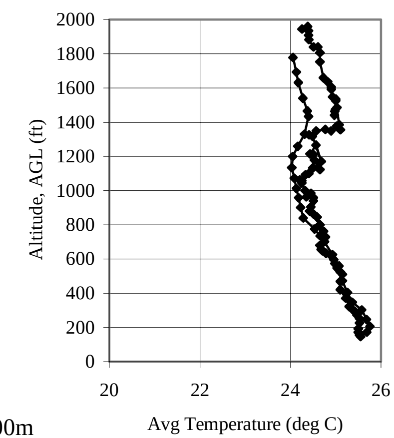
ATR AeroTech Research (U.S.A.), Inc.

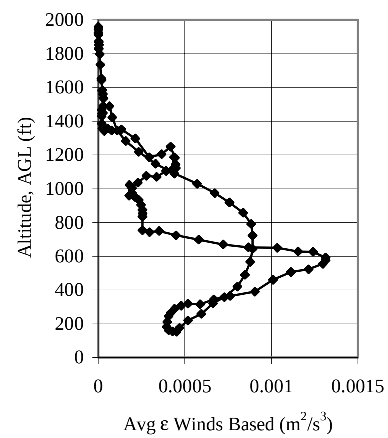












<u>R162 - Run 01</u>
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

APGAStart = 3000m
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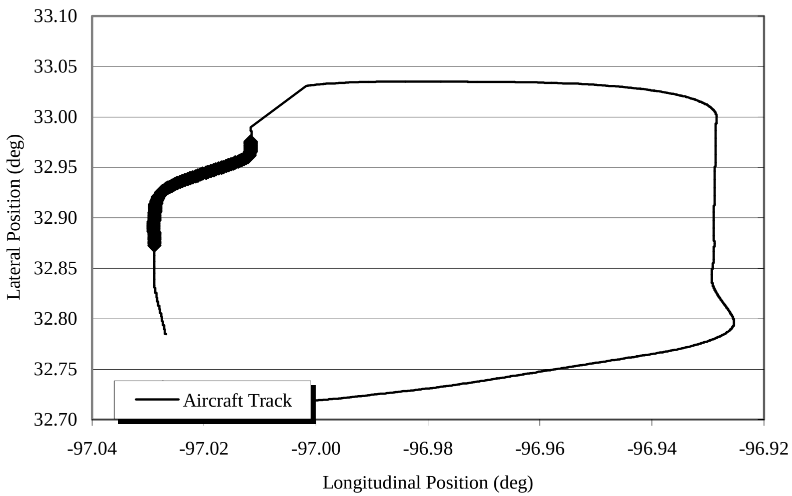
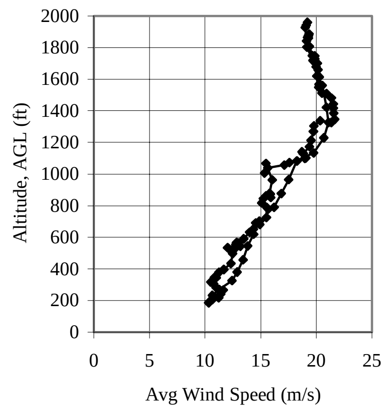
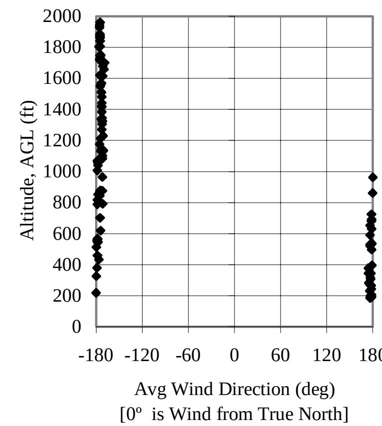
APGAHigh = 600m

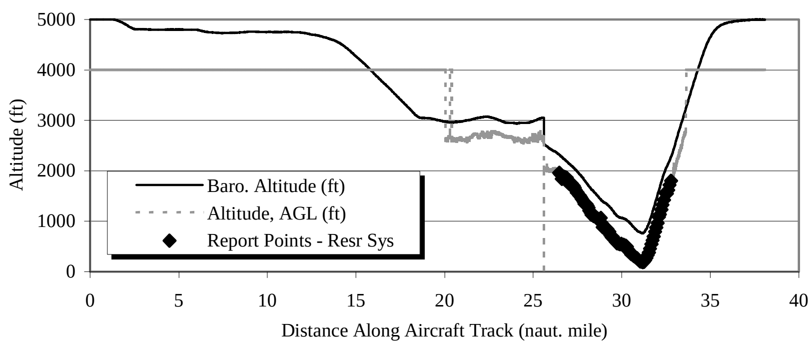
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

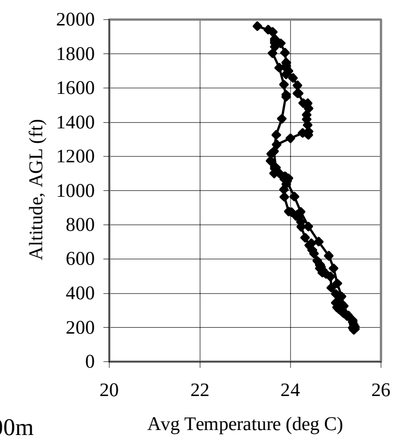
AeroTech Research (U.S.A.), Inc.

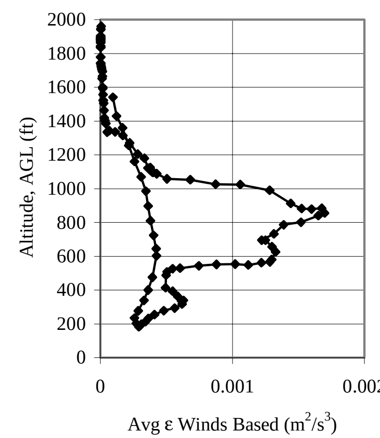










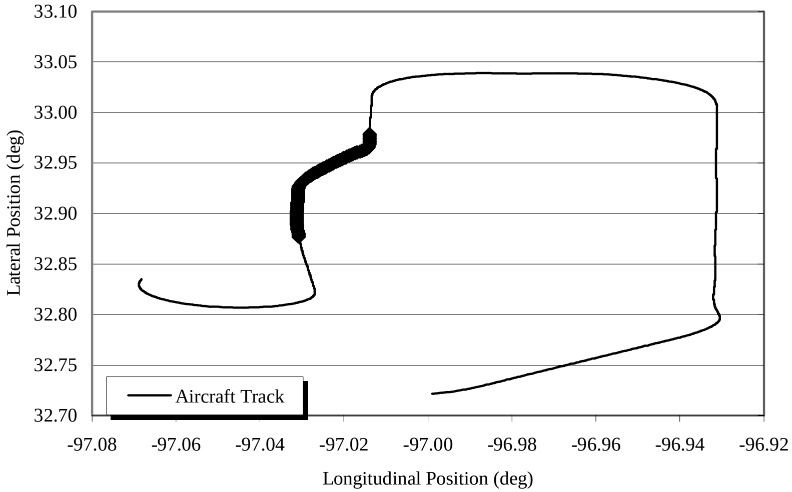


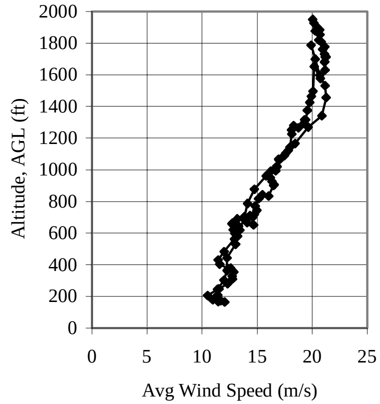
R162 - Run 02
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

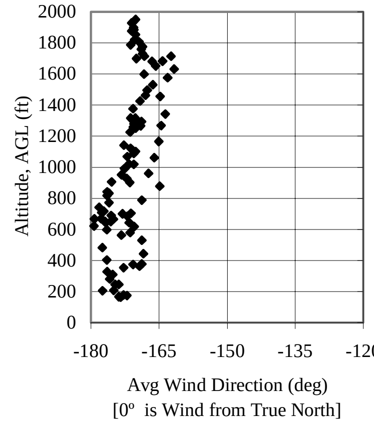
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

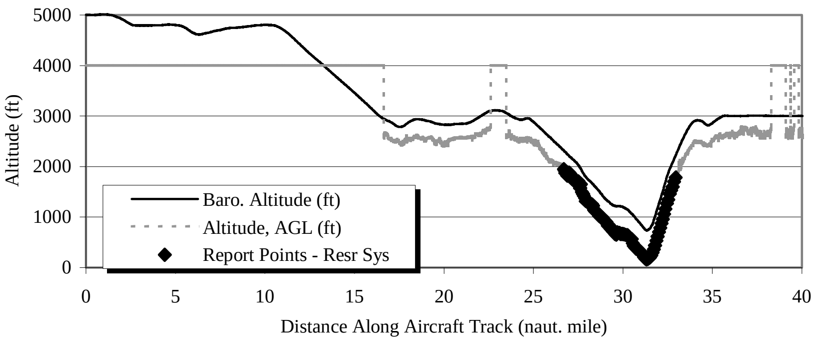
APGATMP = 5s   APGAWNS = 5s
APGAEDR = 20s   APGAWND = 5s

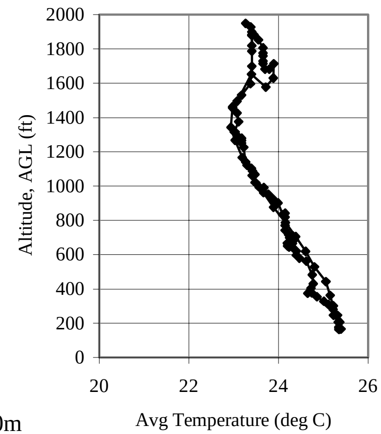
AeroTech Research (U.S.A.), Inc.

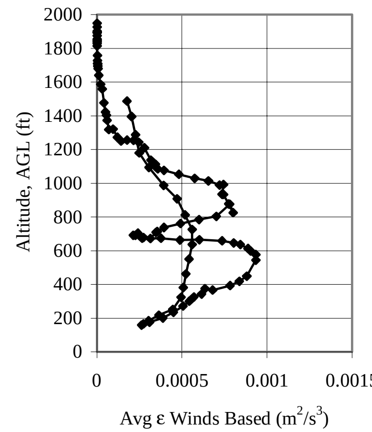












R162 - Run 03

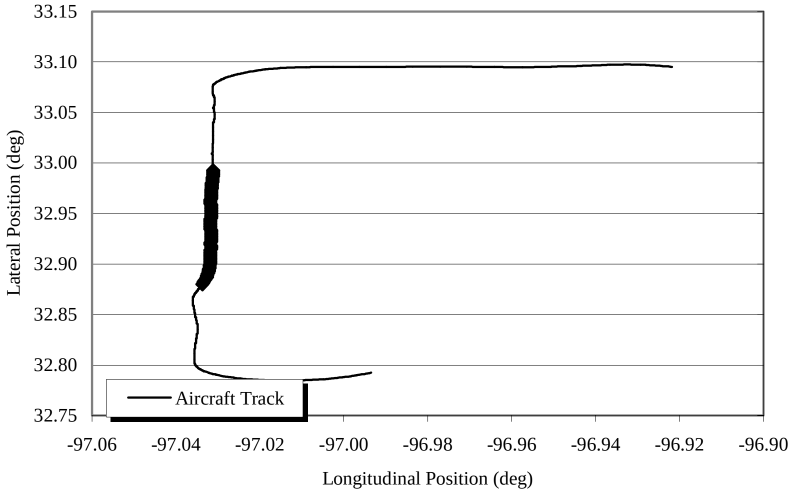
Atmospheric Profile Generation Algorithm

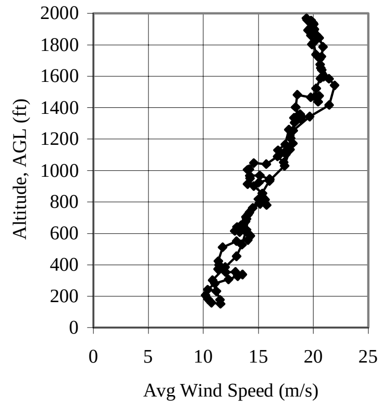
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

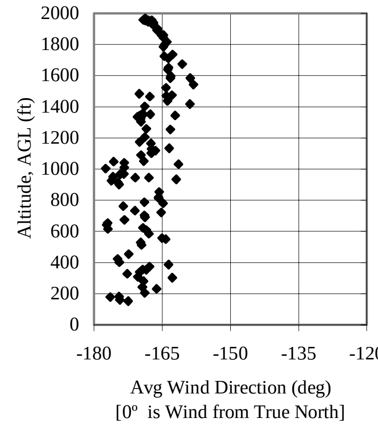
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

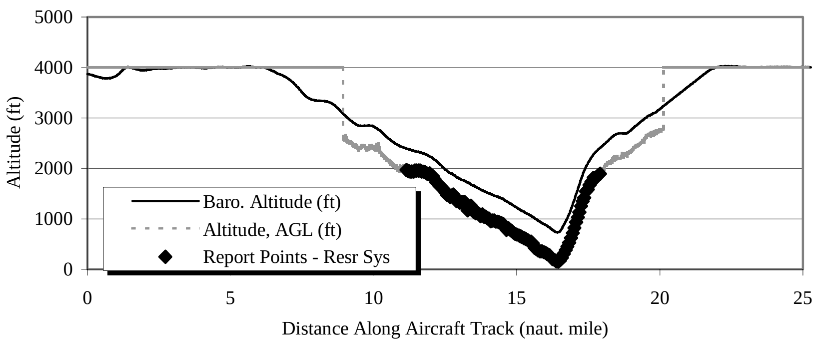
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

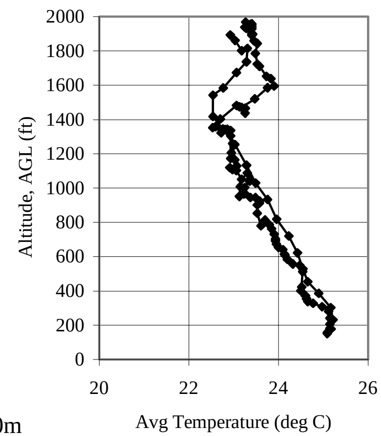
AeroTech Research (U.S.A.), Inc.

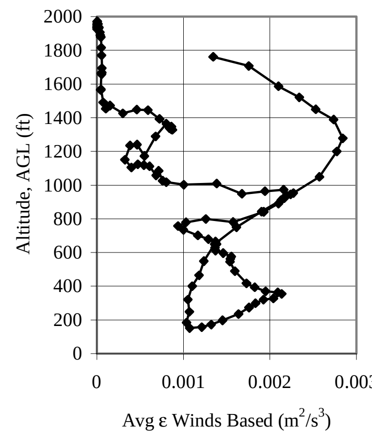










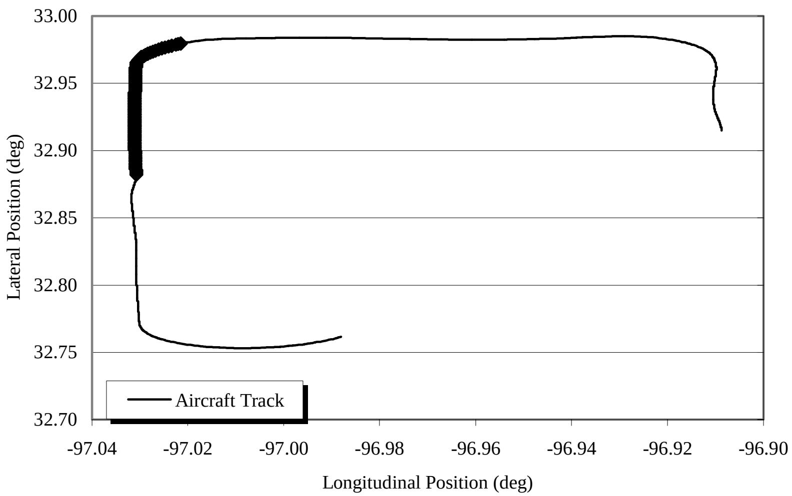


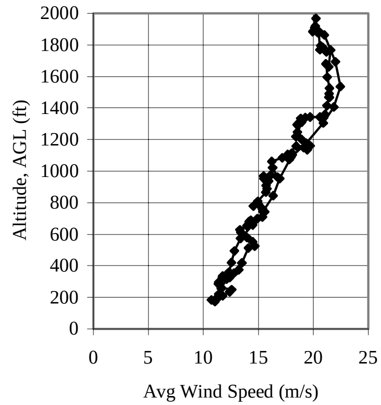
<u>R162 - Run 04</u>
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

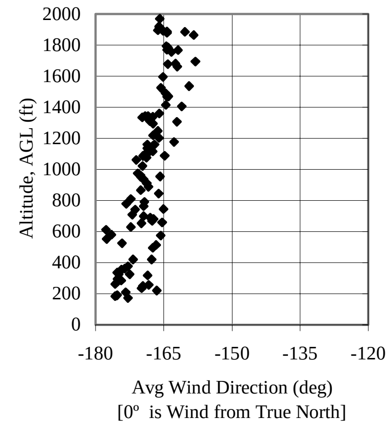
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

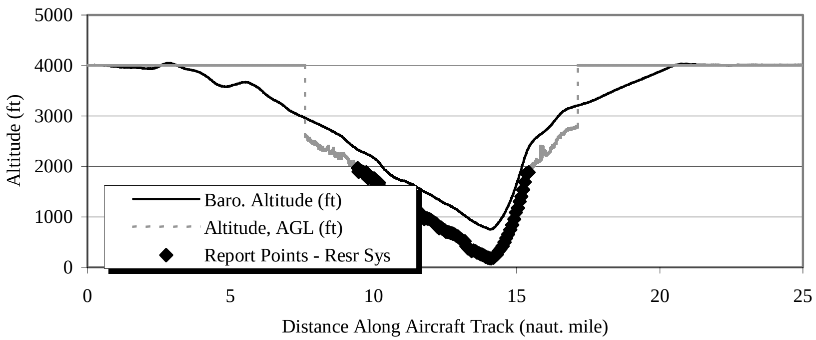
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

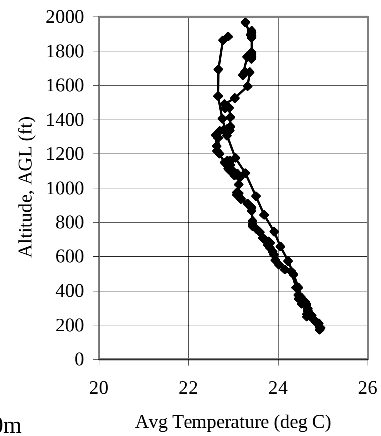
AeroTech Research (U.S.A.), Inc.

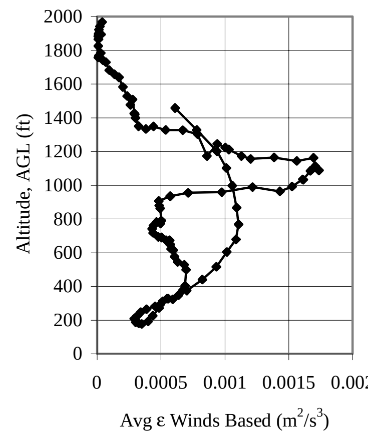












<u>**R162 - Run 05**</u>

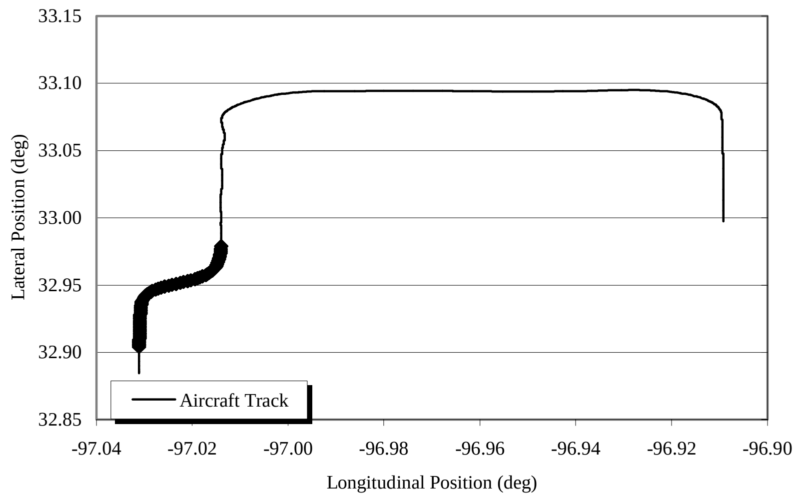
Atmospheric Profile Generation Algorithm

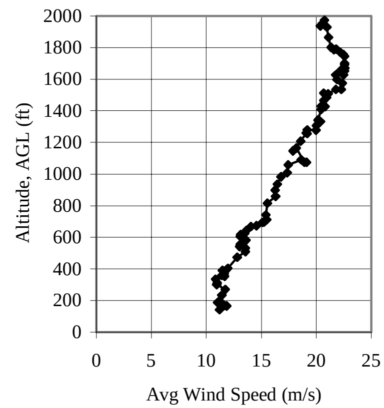
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

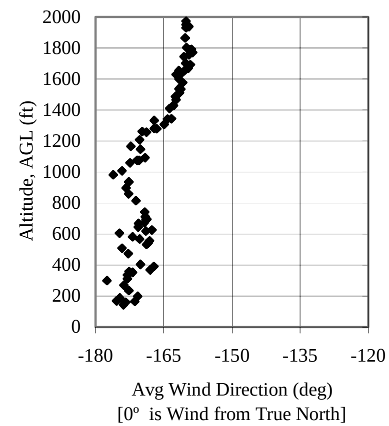
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

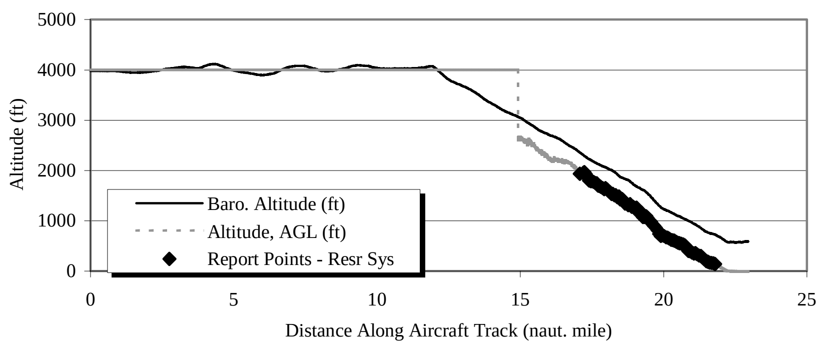
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

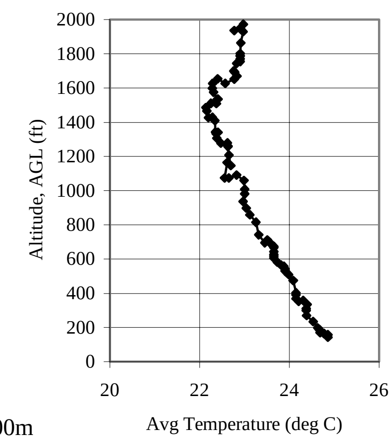
AeroTech Research (U.S.A.), Inc.

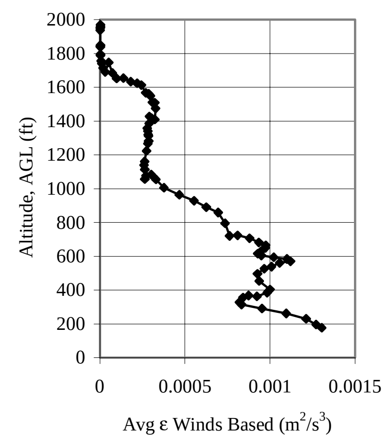












<u>R162 - Run 06</u>

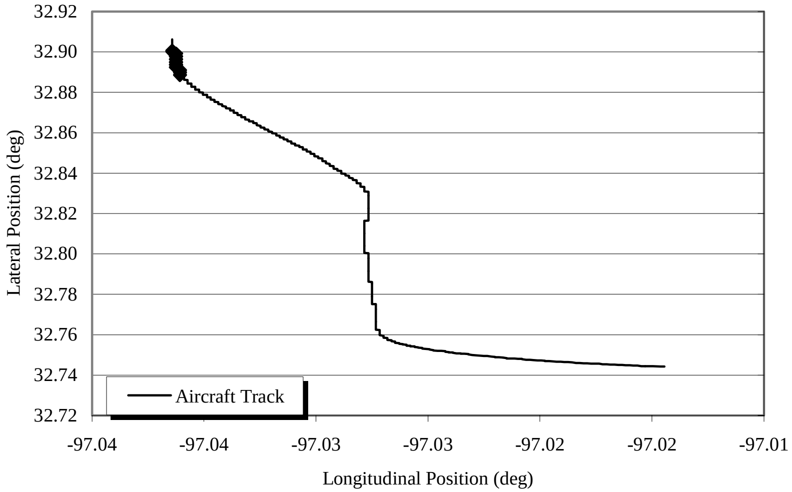
Atmospheric Profile Generation Algorithm

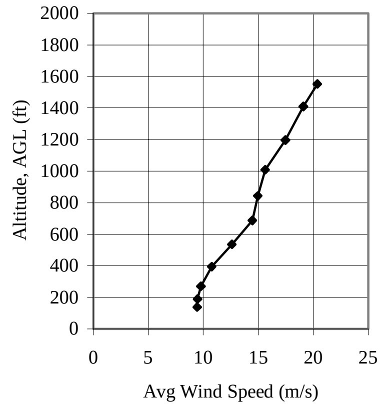
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

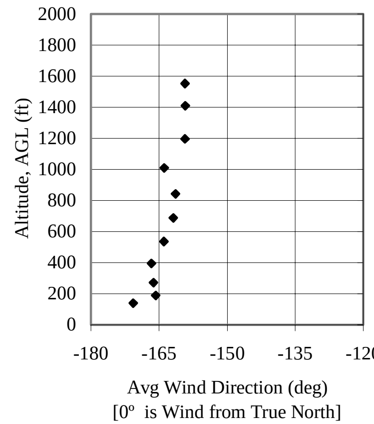
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

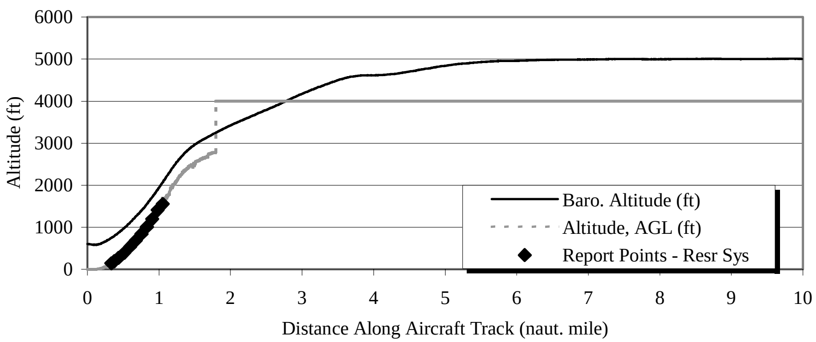
APGATMP = 5s   APGAWNS = 5s
APGAEDR = 20s   APGAWND = 5s

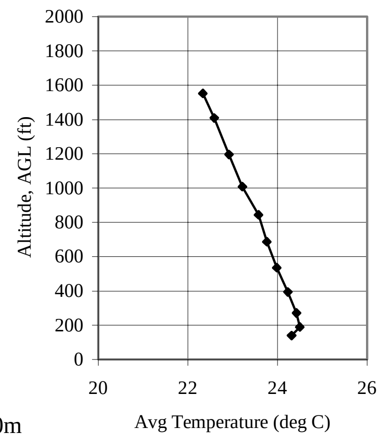
AeroTech Research (U.S.A.), Inc.

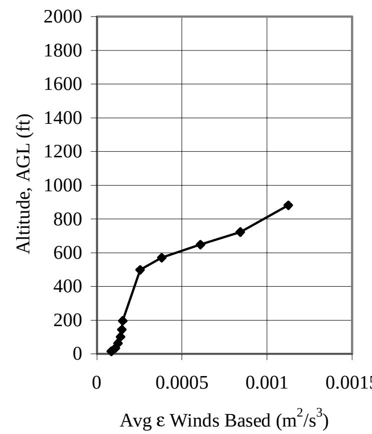












R162 - Run 07

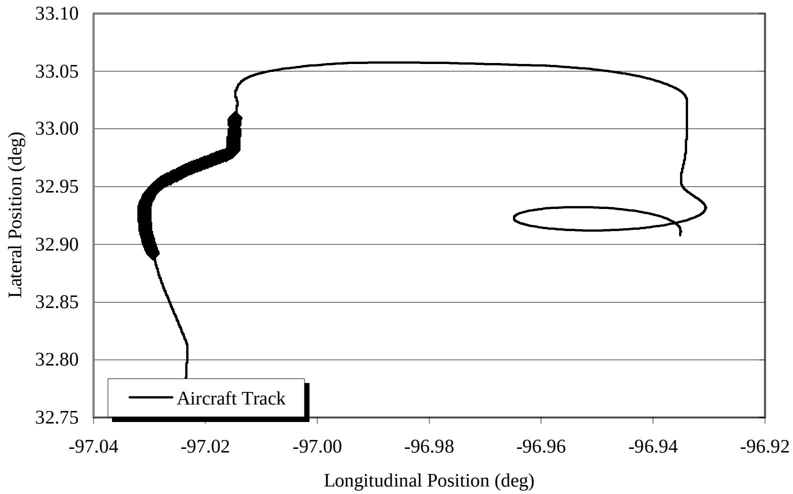
Atmospheric Profile Generation Algorithm

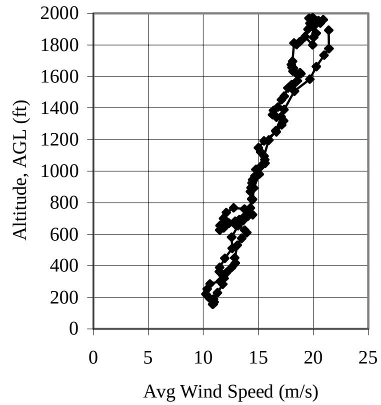
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

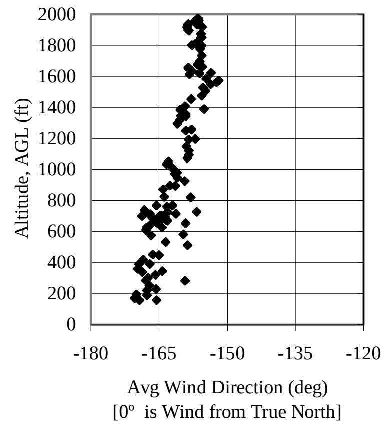
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

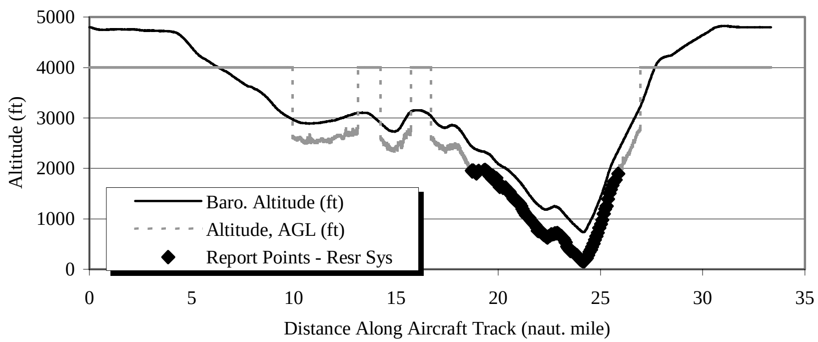
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

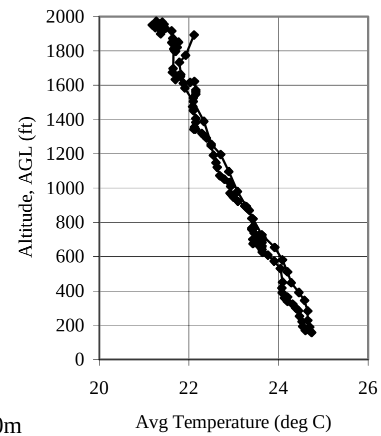
AeroTech Research (U.S.A.), Inc.

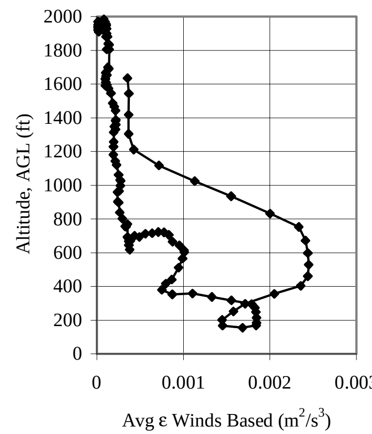












R162 - Run 08

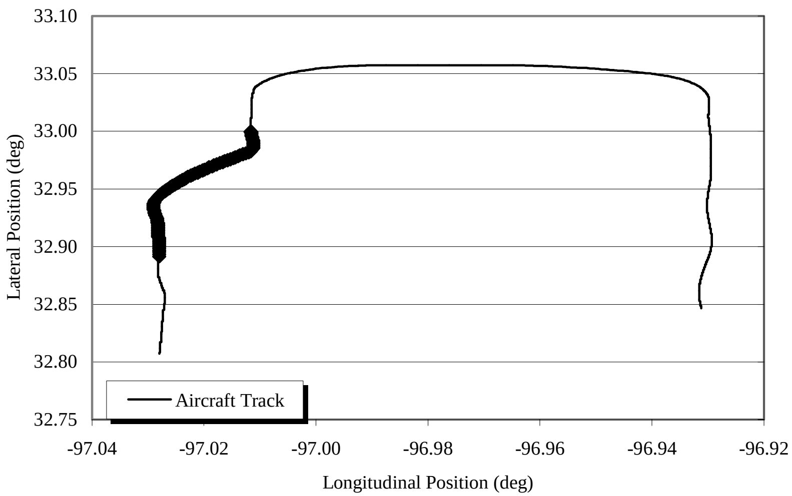
Atmospheric Profile Generation Algorithm

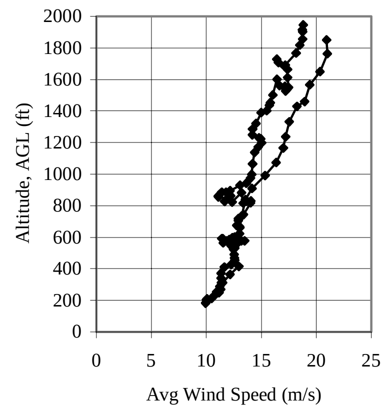
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

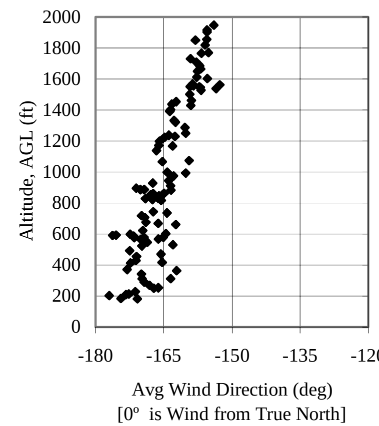
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

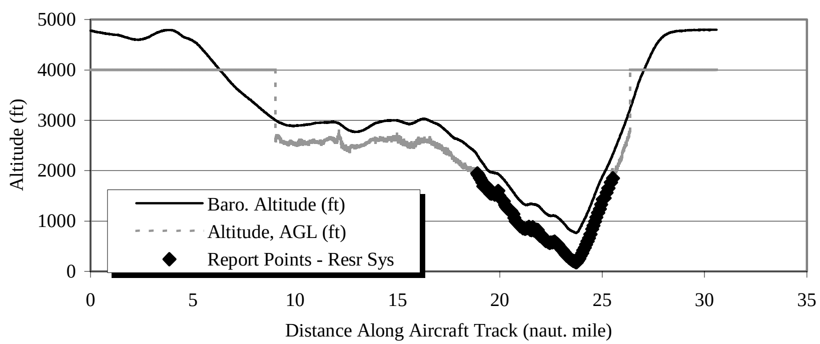
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

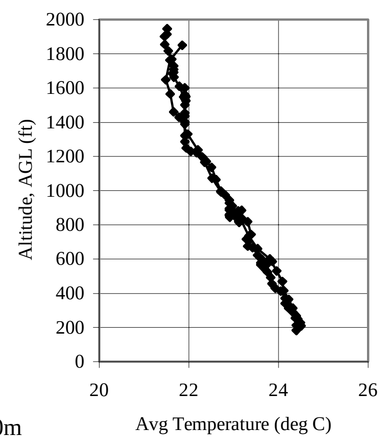
AeroTech Research (U.S.A.), Inc.

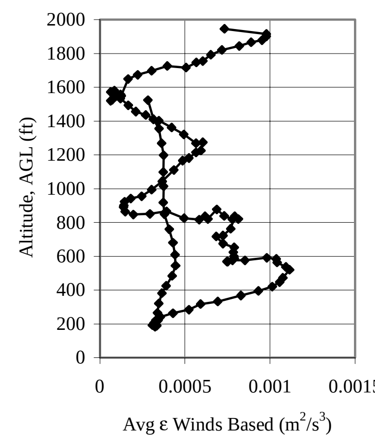










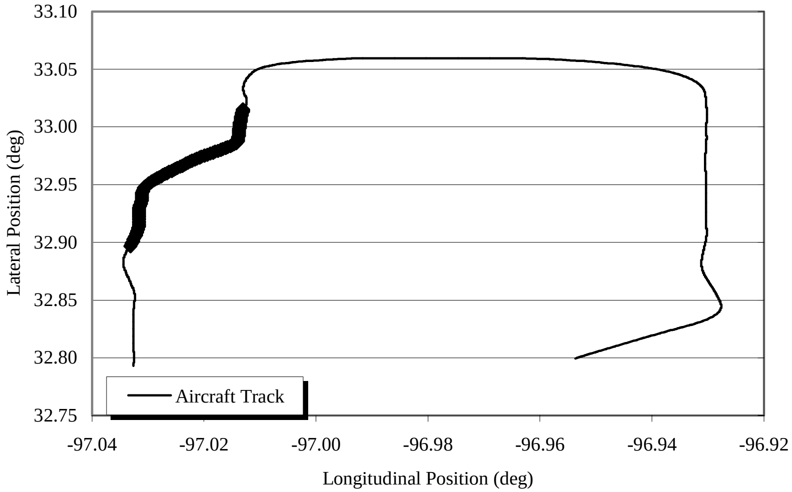


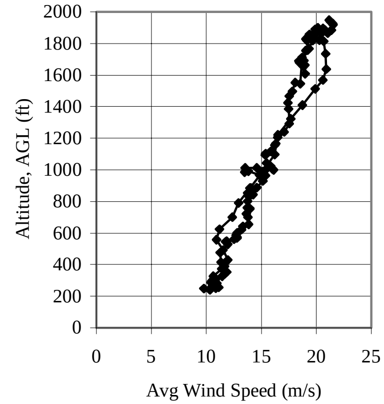
R162 - Run 09
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

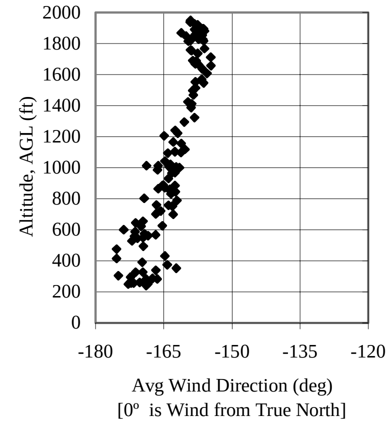
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

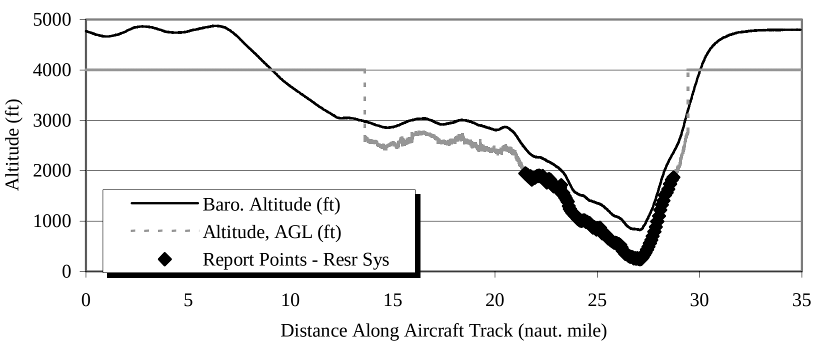
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

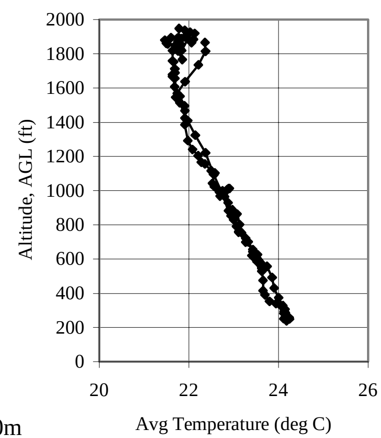
AeroTech Research (U.S.A.), Inc.

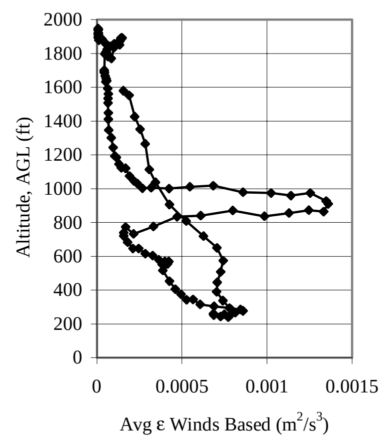












R162 - Run 10

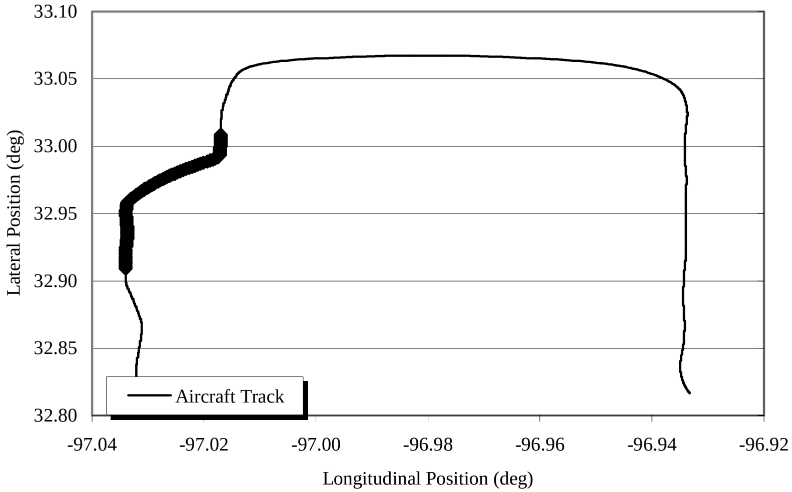
Atmospheric Profile Generation Algorithm

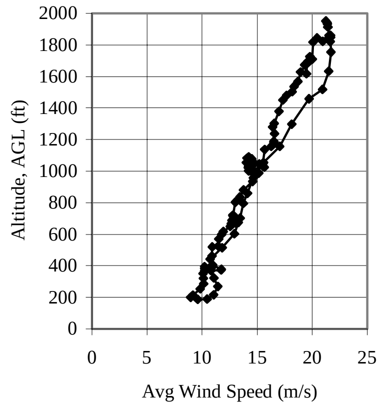
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

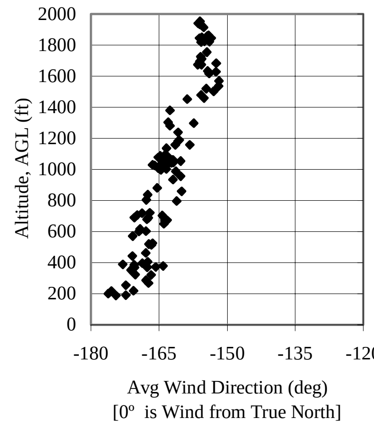
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

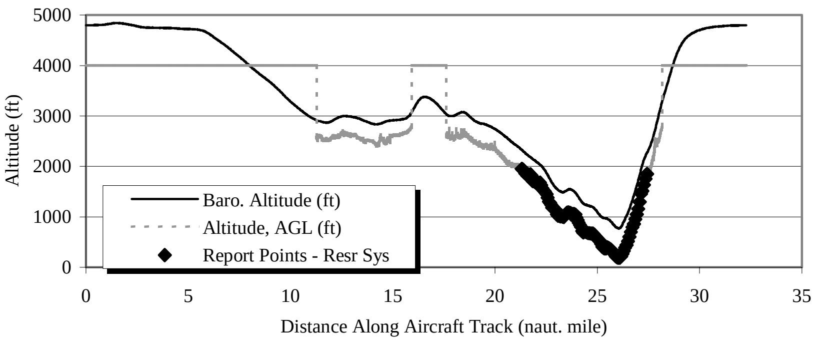
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

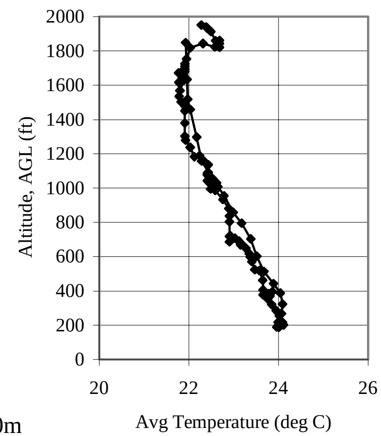
ATR AeroTech Research (U.S.A.), Inc.

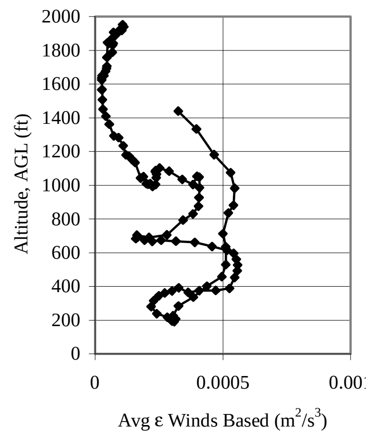












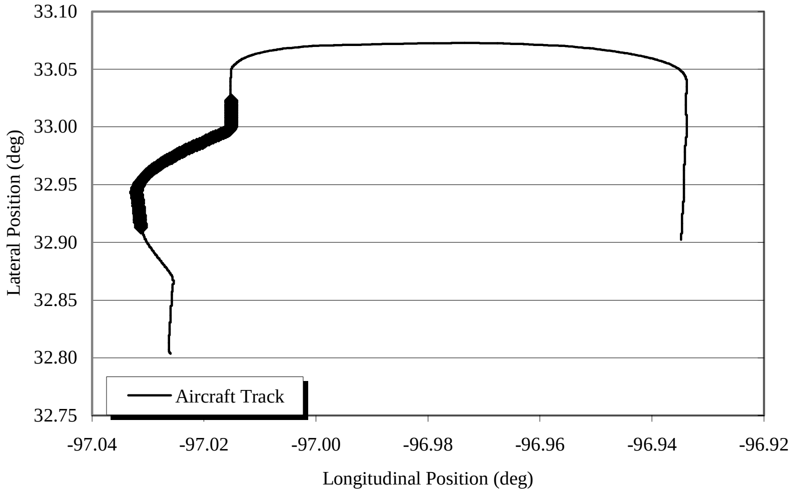
R162 - Run 11
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

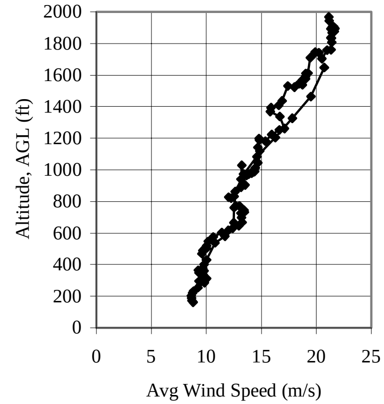
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

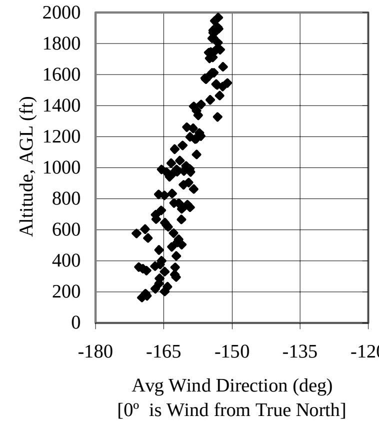
APGATMP = 5s
APGAEDR = 20s

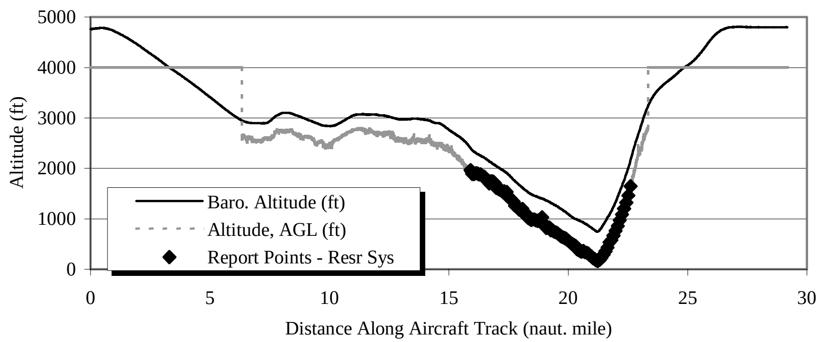
APGAWNS = 5s
APGAWND = 5s

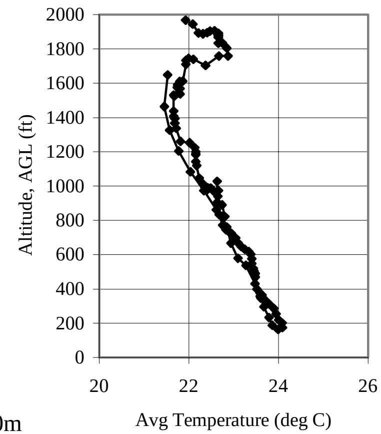
AeroTech Research (U.S.A.), Inc.

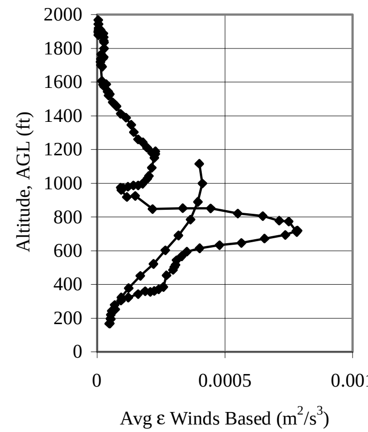










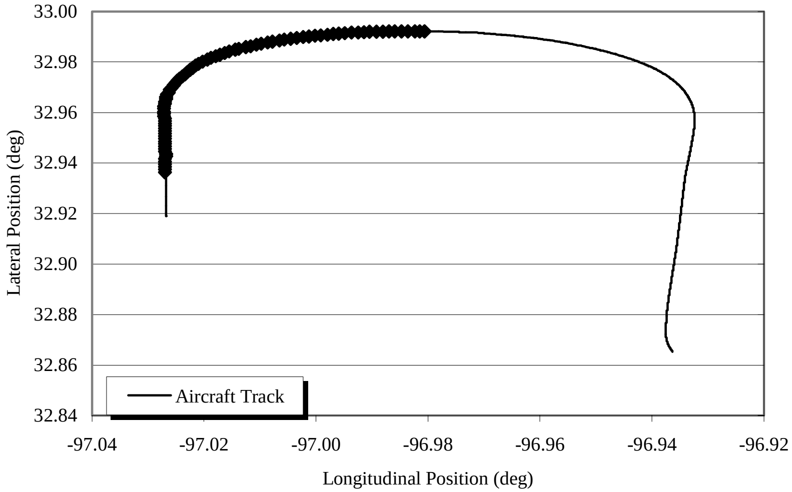


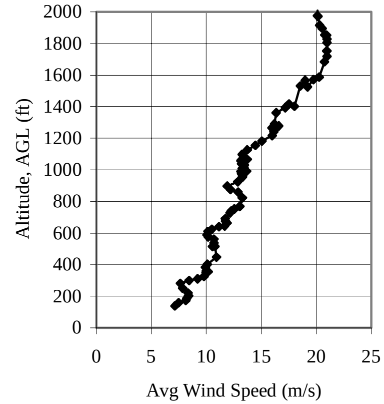
R162 - Run 12
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

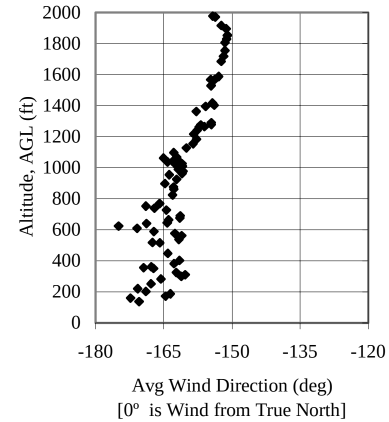
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

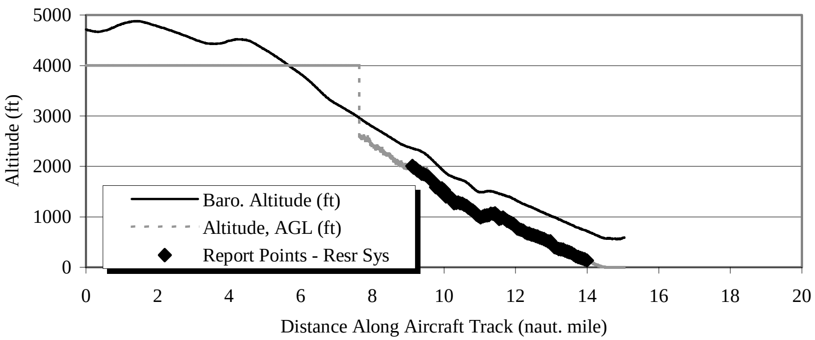
APGATMP = 5s   APGAWNS = 5s
APGAEDR = 20s   APGAWND = 5s

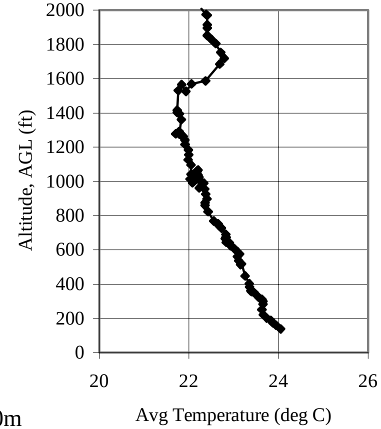
AeroTech Research (U.S.A.), Inc.

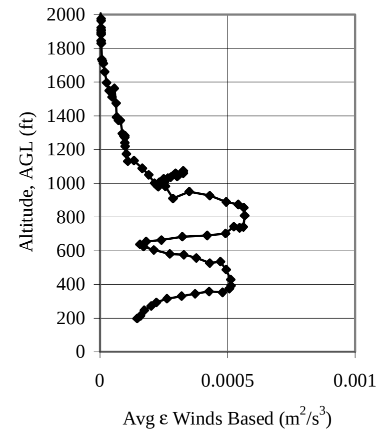










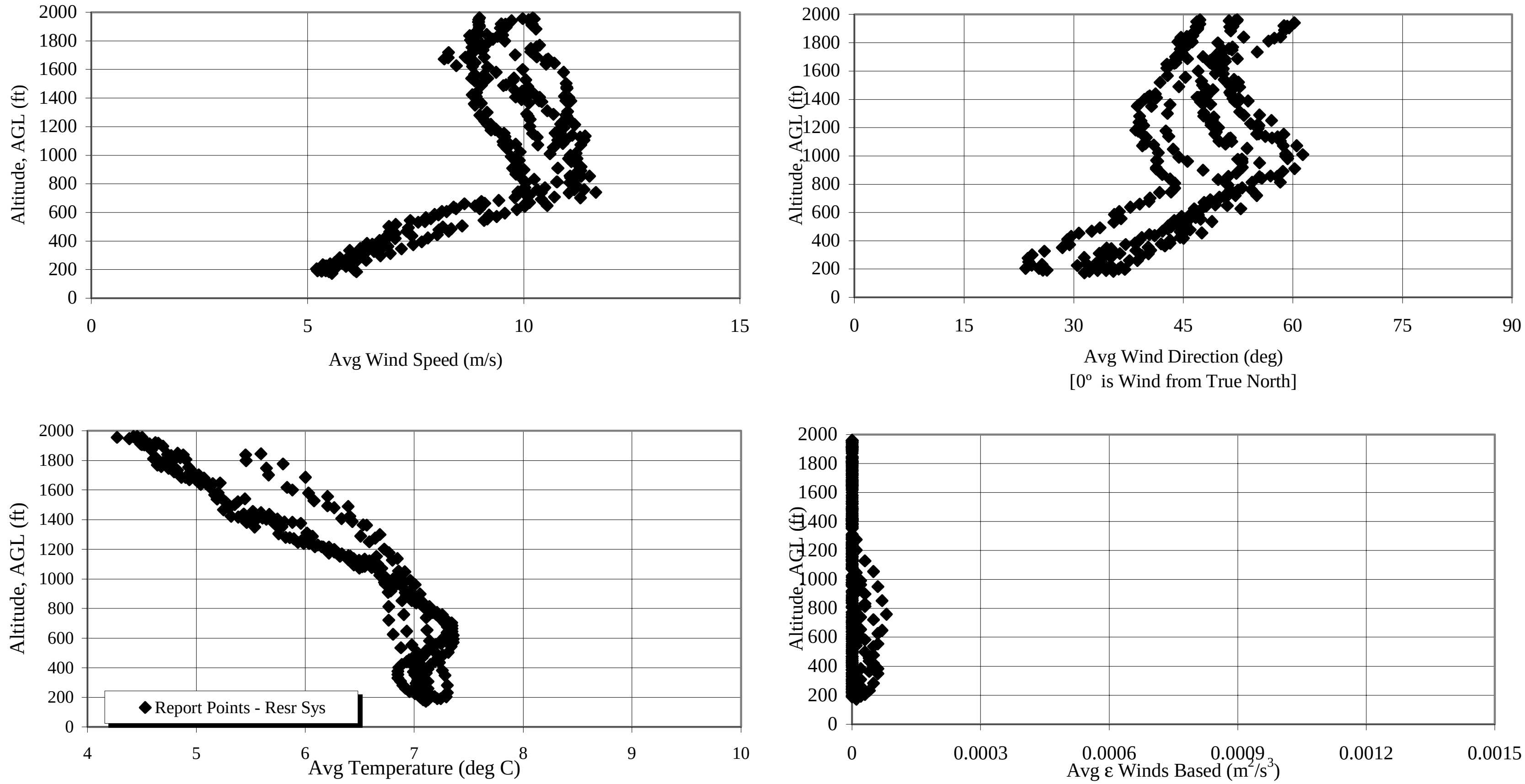


<u>R162 - Run 13</u>
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 4, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



R165 - Summary, Block 1 (30 minute collection - Run 01-03)

Atmospheric Profile Generation Algorithm

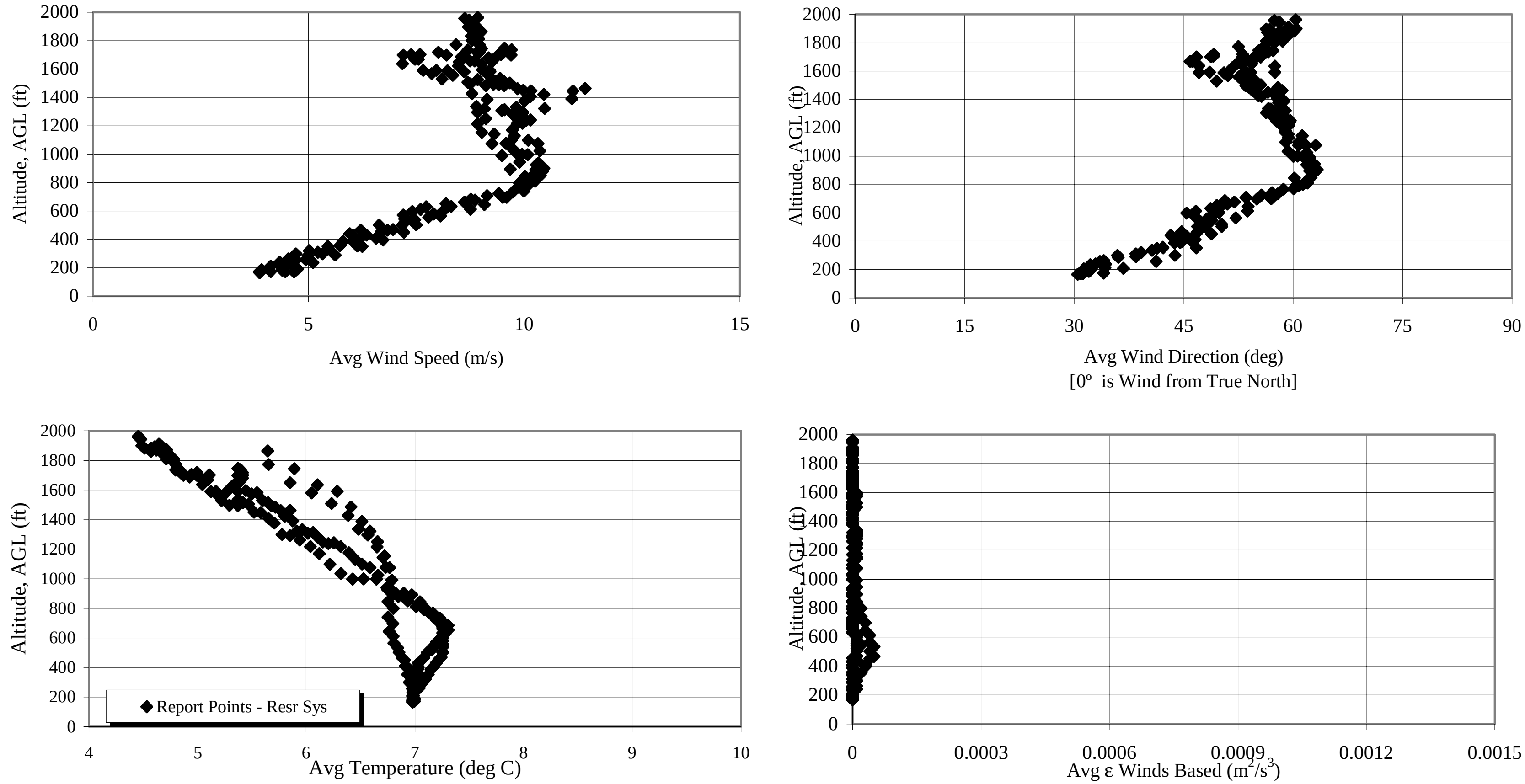
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



R165 - Summary, Block 2 (30 minute collection - Run 04-05)

Atmospheric Profile Generation Algorithm

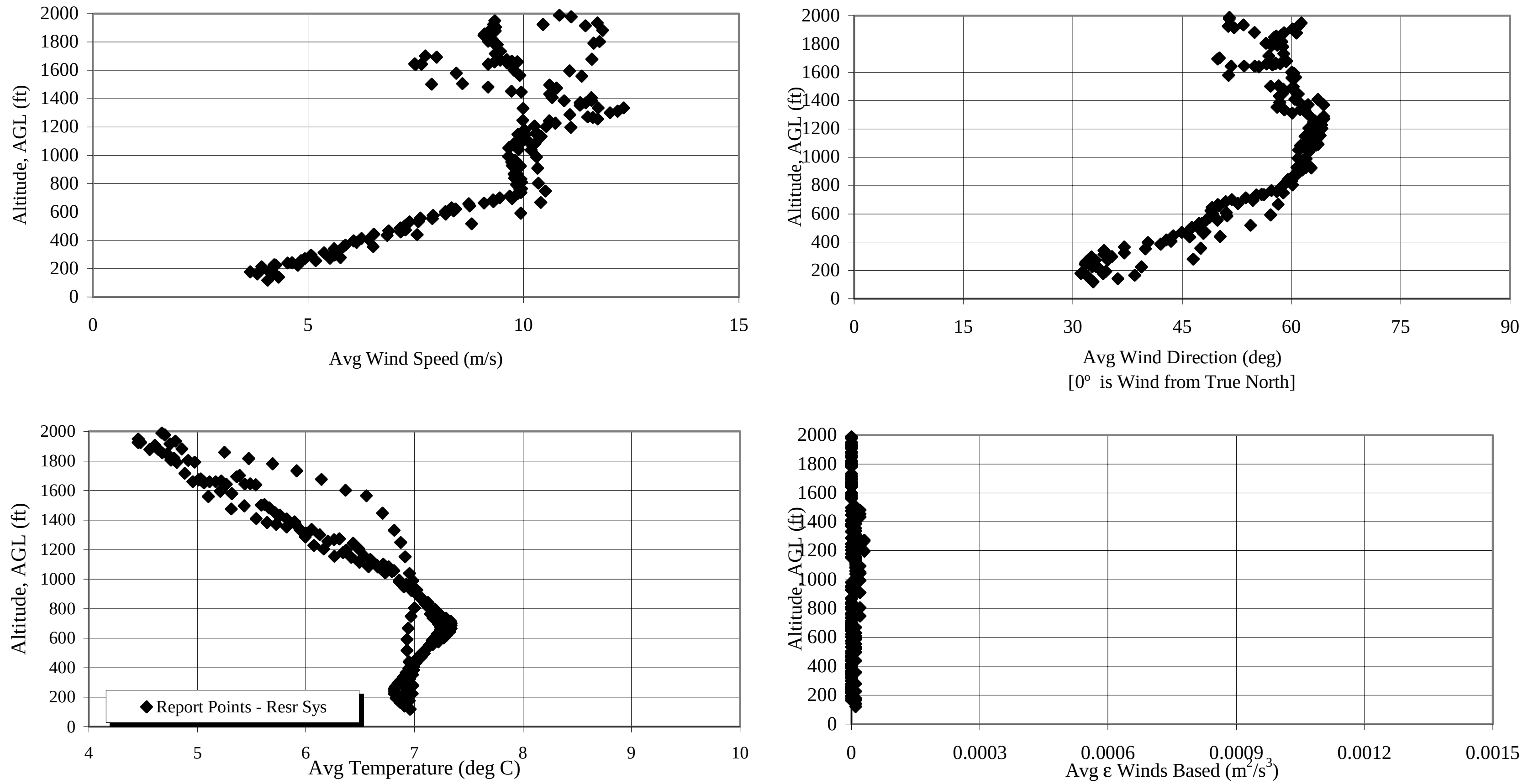
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



<u>R165 - Summary, Block 3 (30 minute collection - Run 06-07)</u>

Atmospheric Profile Generation Algorithm

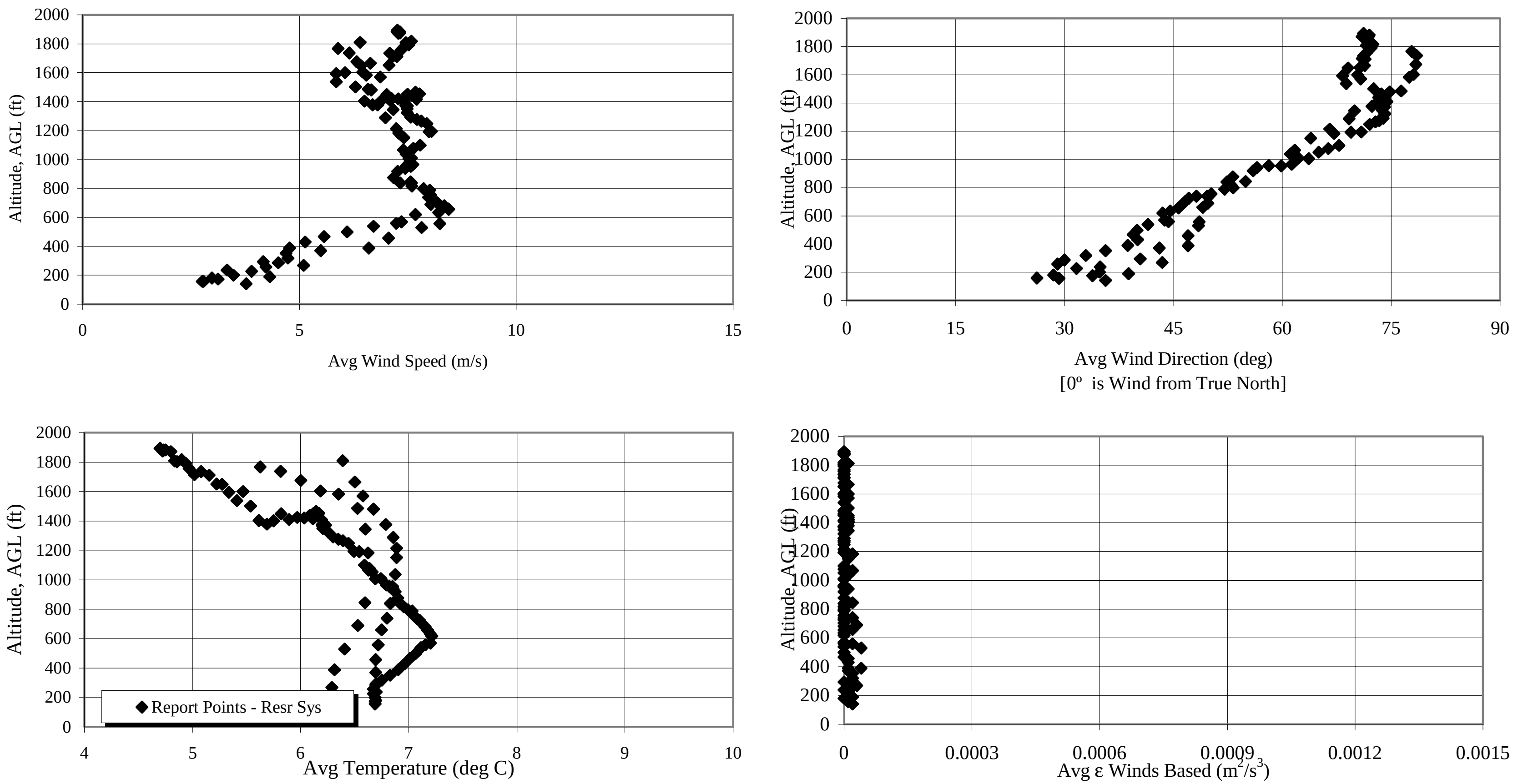
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



<u>R165 - Summary, Block 4 (30 minute collection - Run 08-09)</u>

Atmospheric Profile Generation Algorithm

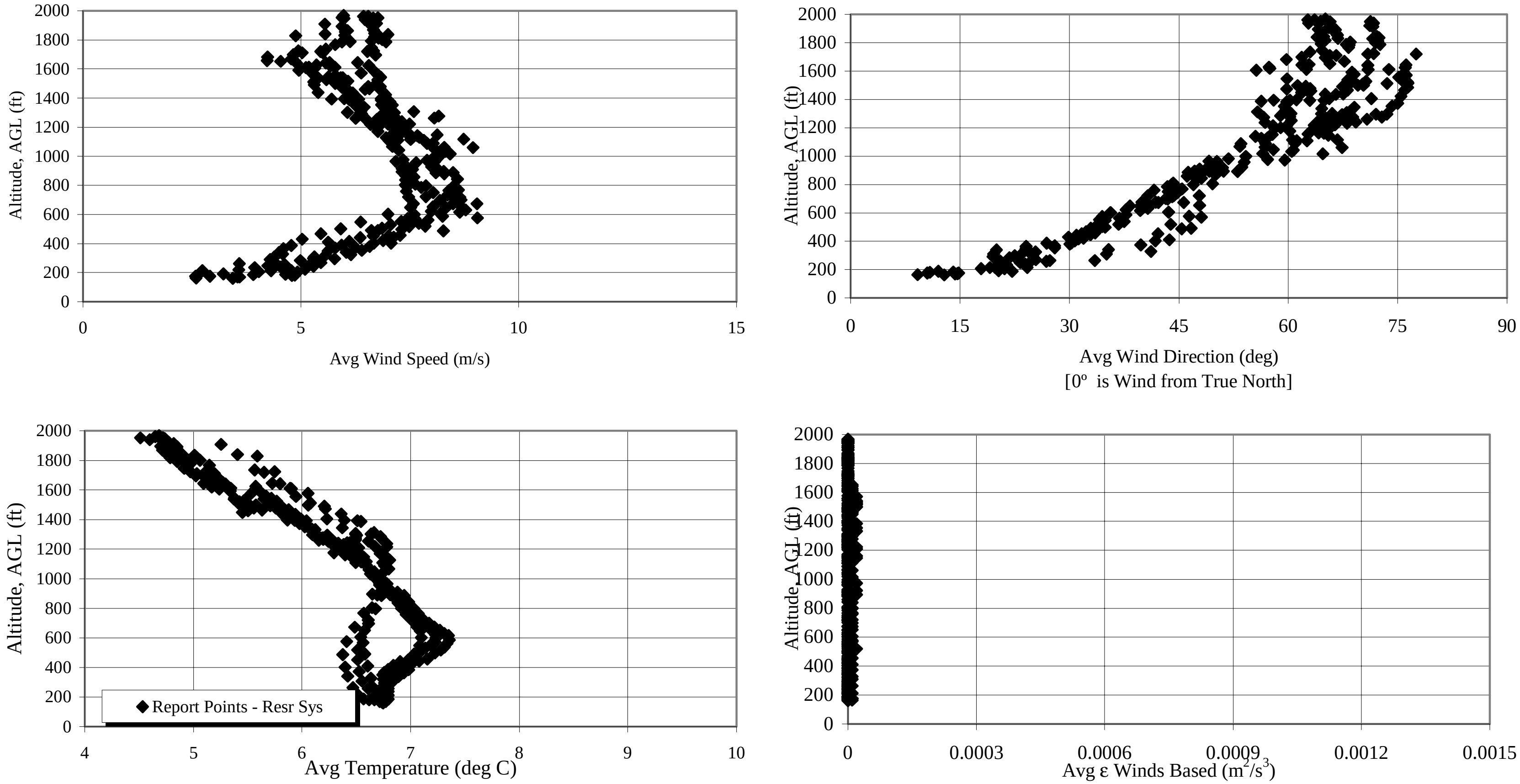
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



<u>R165 - Summary, Block 5 (30 minute collection - Run 10-12)</u>

Atmospheric Profile Generation Algorithm

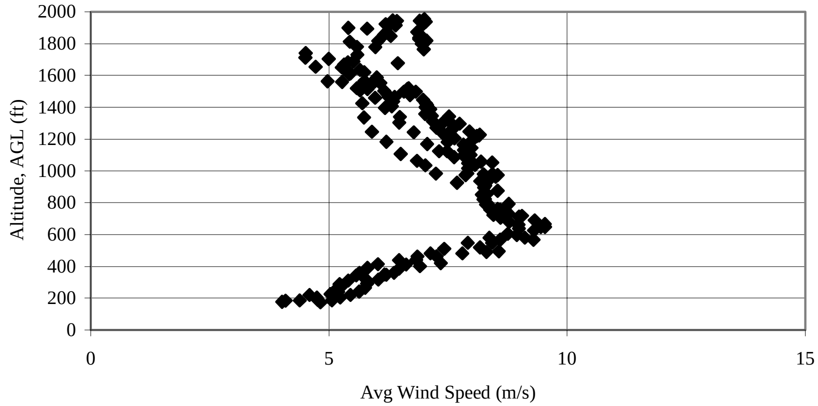
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

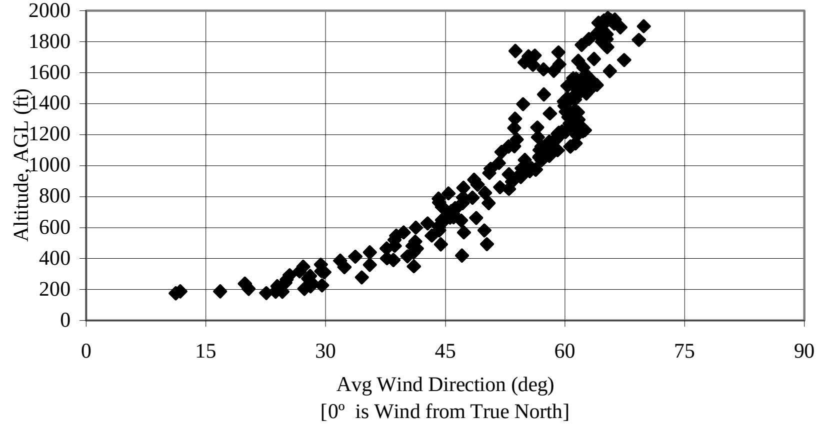
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

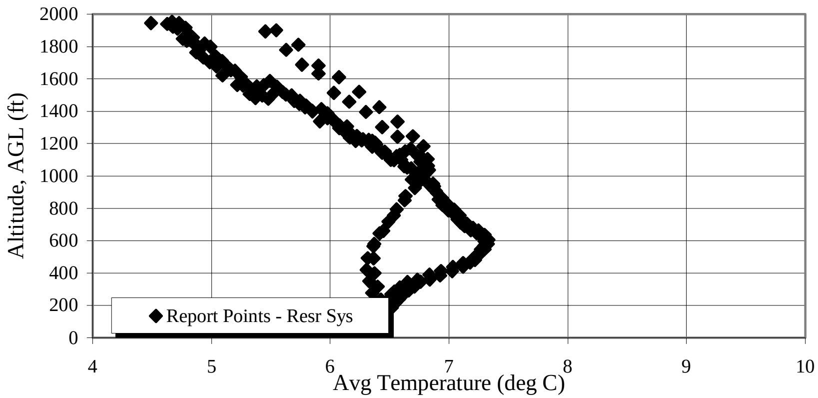
APGATMP = 5s
APGAEDR = 20s

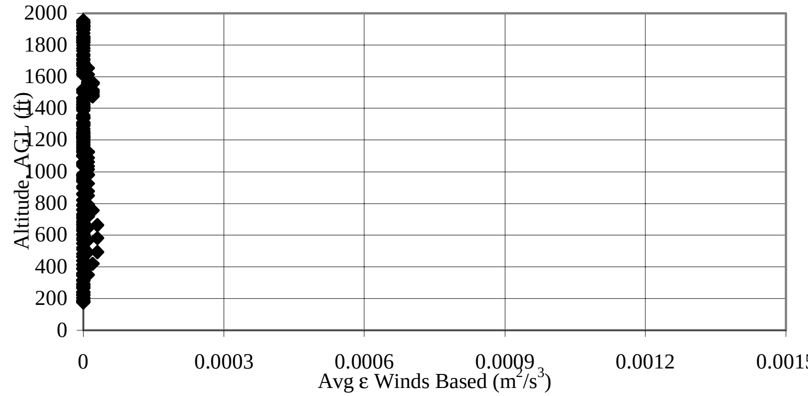
APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.









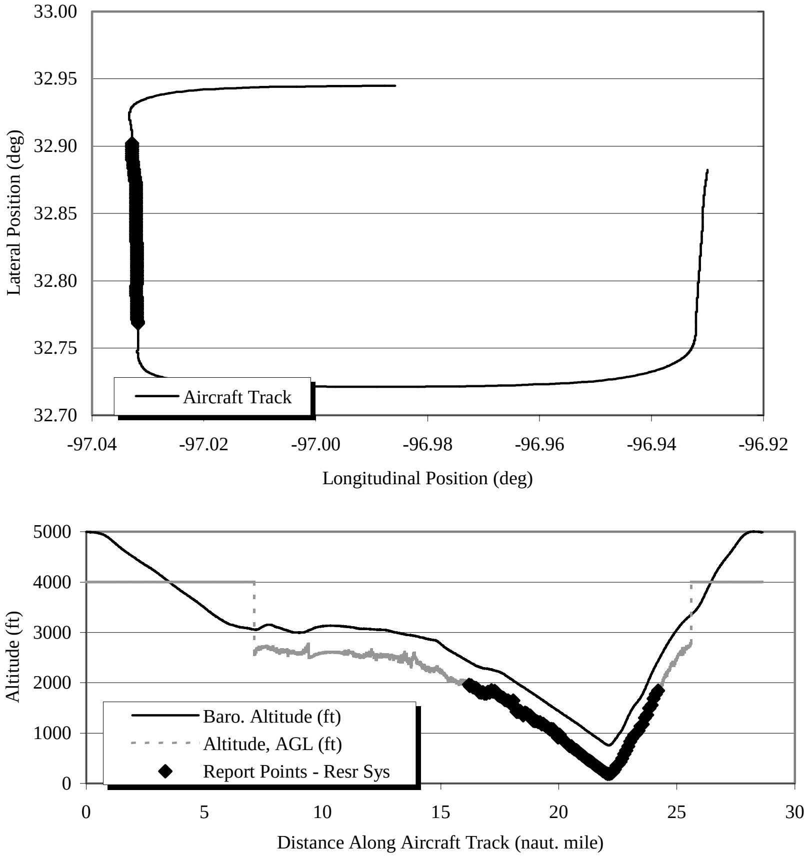
R165 - Summary, Block 6 (30 minute collection - Run 13-14)
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

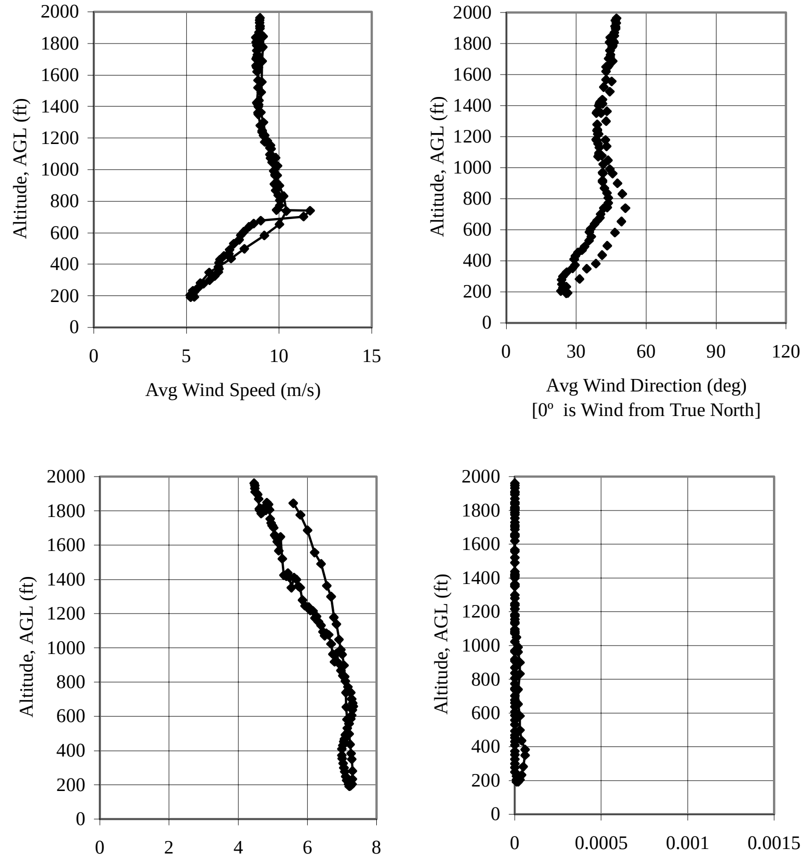
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

AeroTech Research (U.S.A.), Inc.



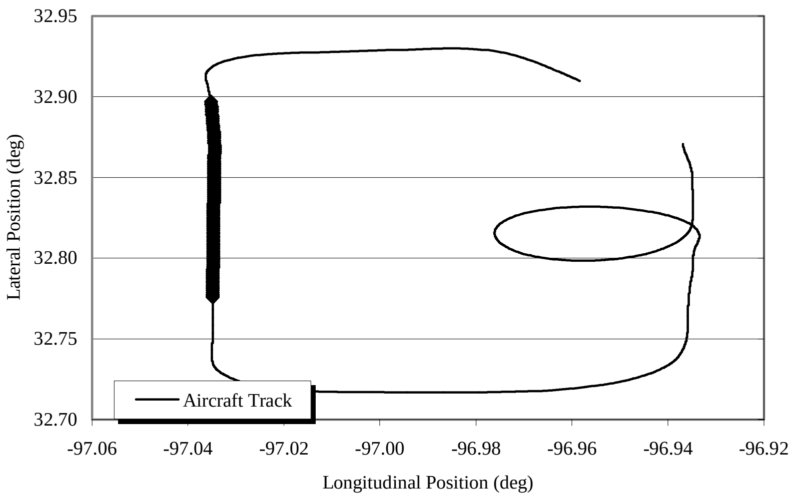


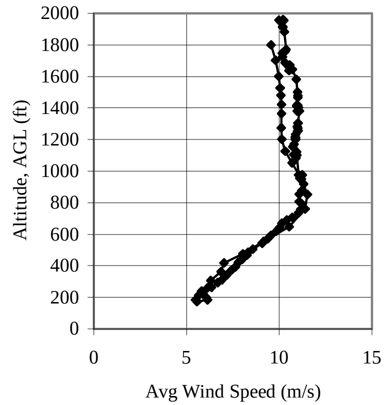
R165 - Run 01
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

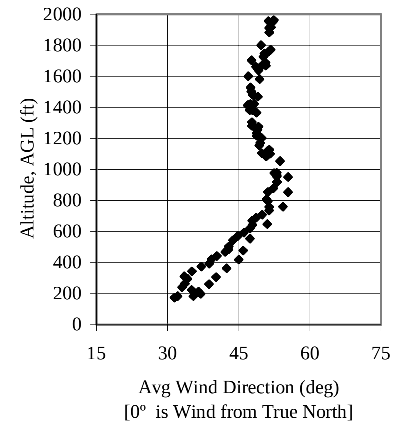
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

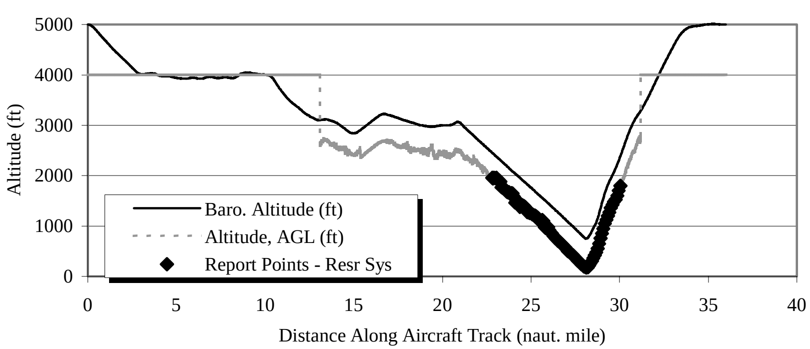
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

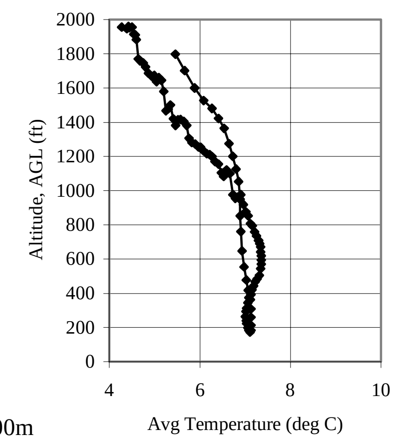
AeroTech Research (U.S.A.), Inc.

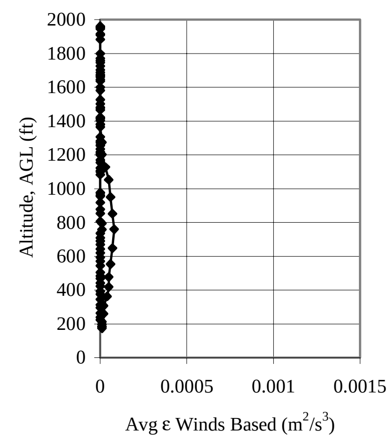












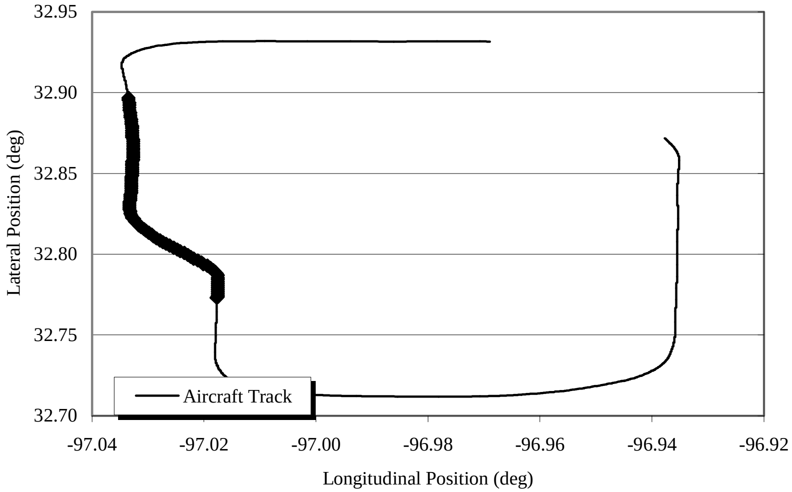
<u>R165 - Run 02</u>
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

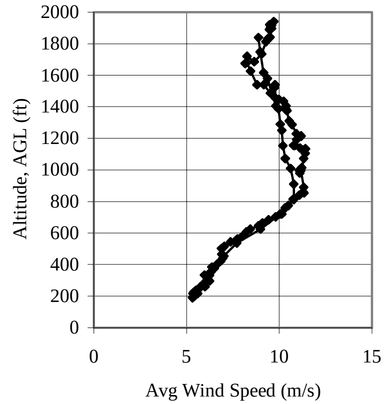
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

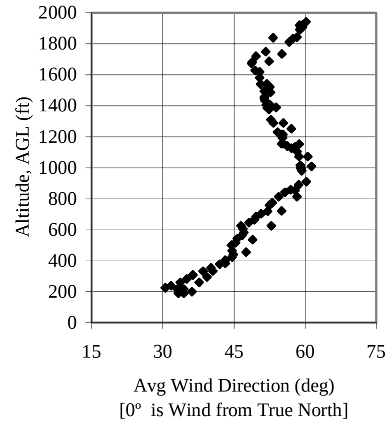
APGATMP = 5s
APGAEDR = 20s

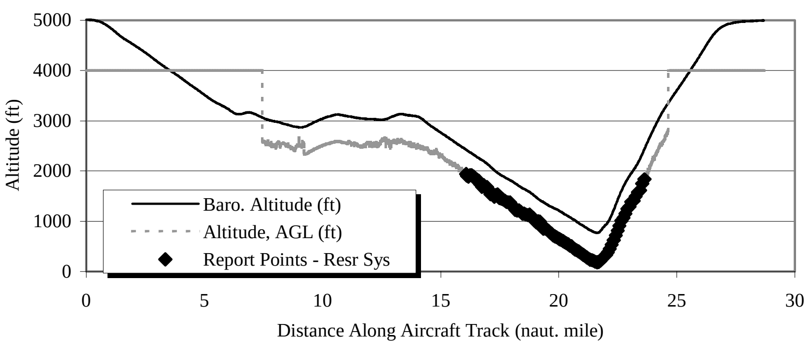
APGAWNS = 5s
APGAWND = 5s

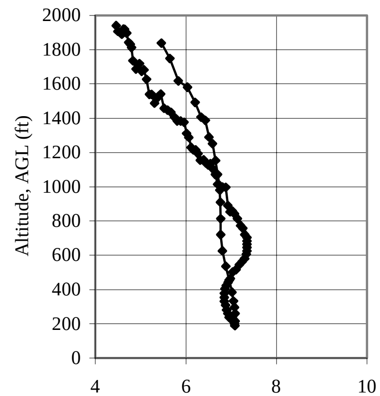
AeroTech Research (U.S.A.), Inc.

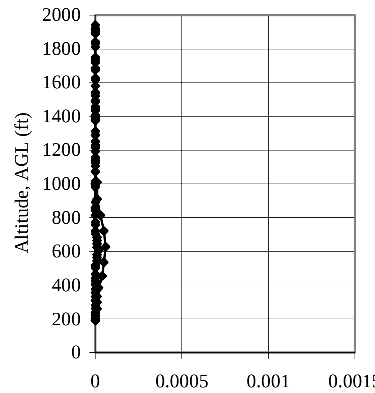










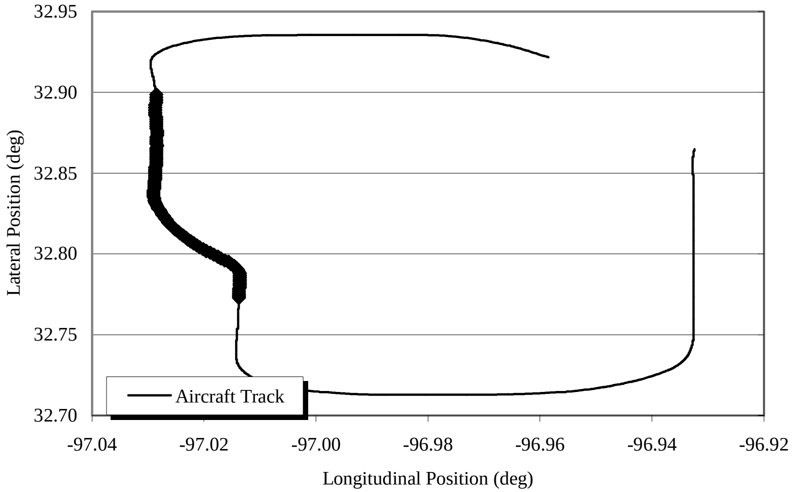


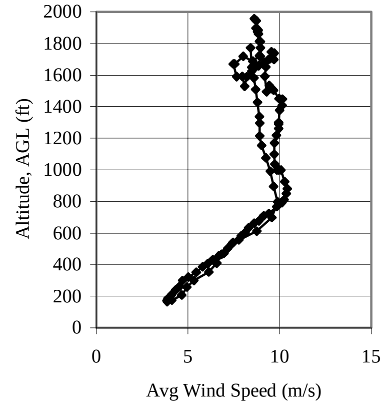
R165 - Run 03
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

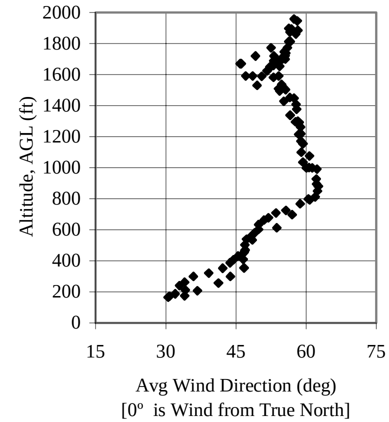
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

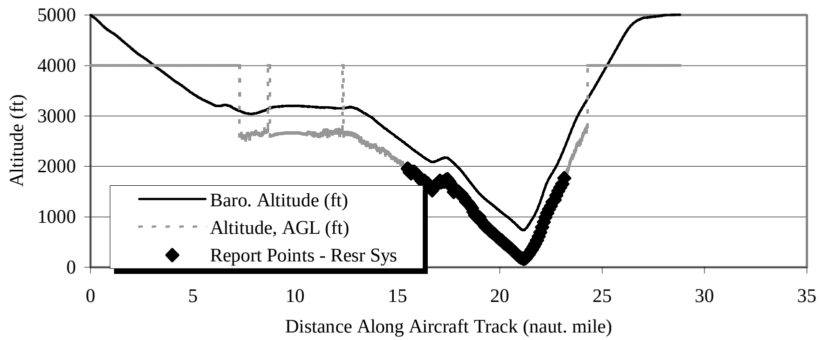
APGATMP = 5s   APGAWNS = 5s
APGAEDR = 20s   APGAWND = 5s

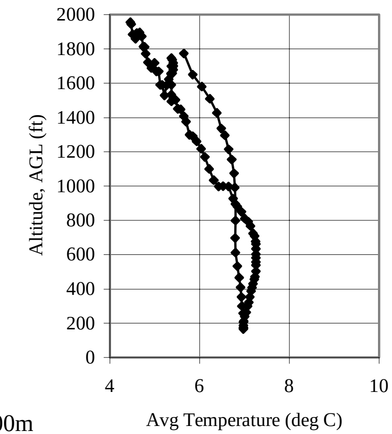
AeroTech Research (U.S.A.), Inc.

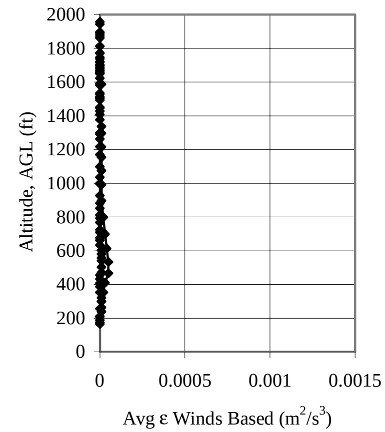












R165 - Run 04

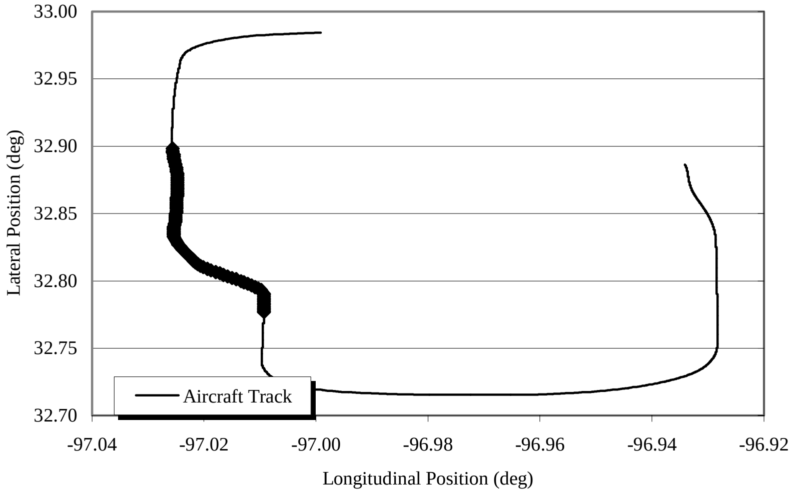
Atmospheric Profile Generation Algorithm

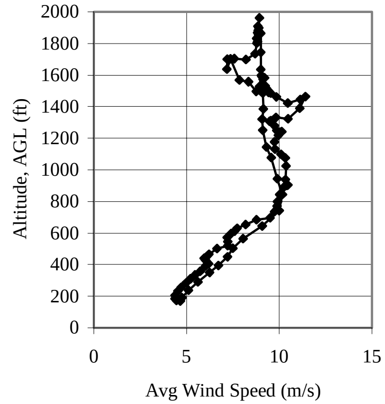
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

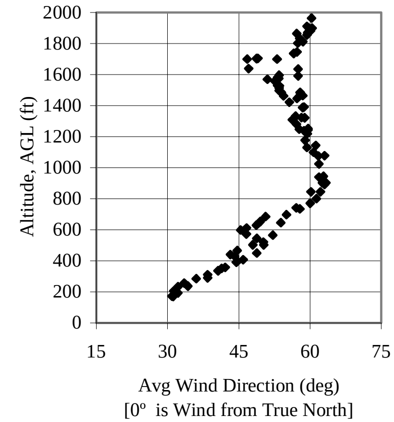
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

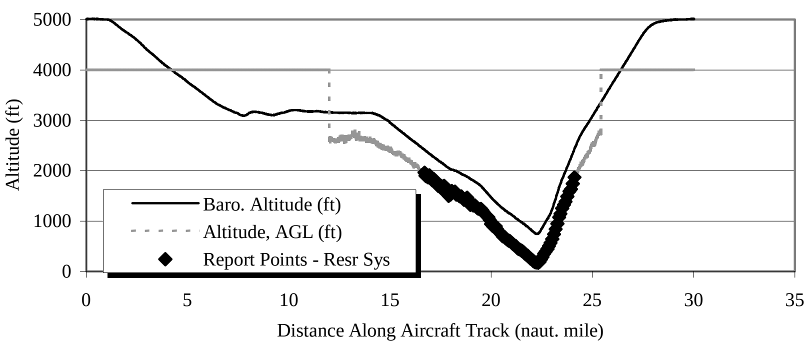
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

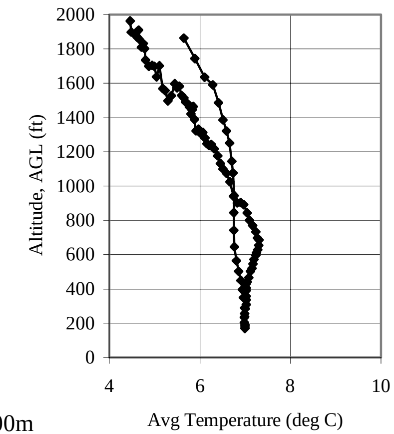
ATR AeroTech Research (U.S.A.), Inc.

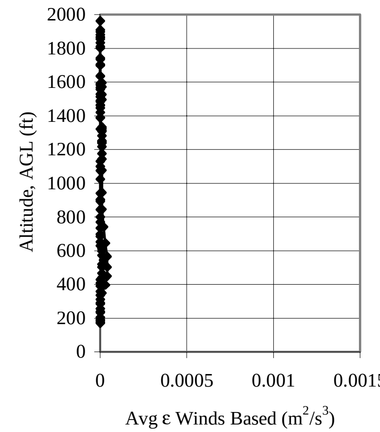












R165 - Run 05

Atmospheric Profile Generation Algorithm

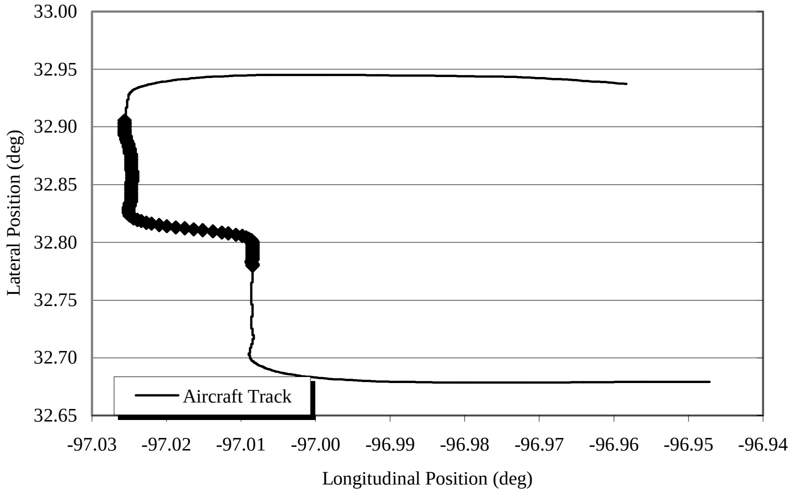
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

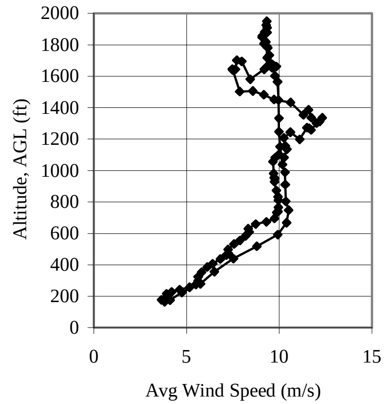
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

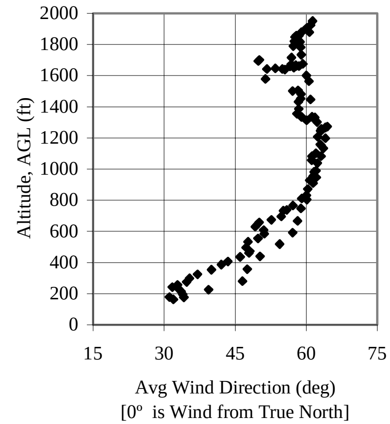
APGATMP = 5s
APGAEDR = 20s

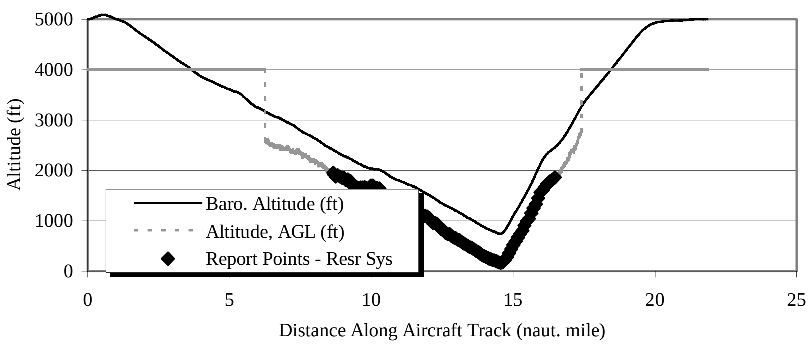
APGAWNS = 5s
APGAWND = 5s

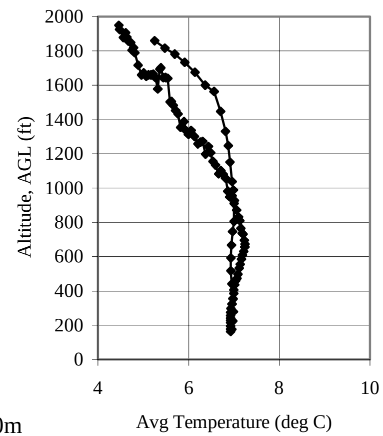
AeroTech Research (U.S.A.), Inc.

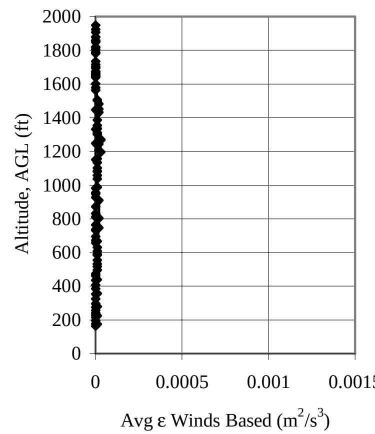












R165 - Run 06

Atmospheric Profile Generation Algorithm

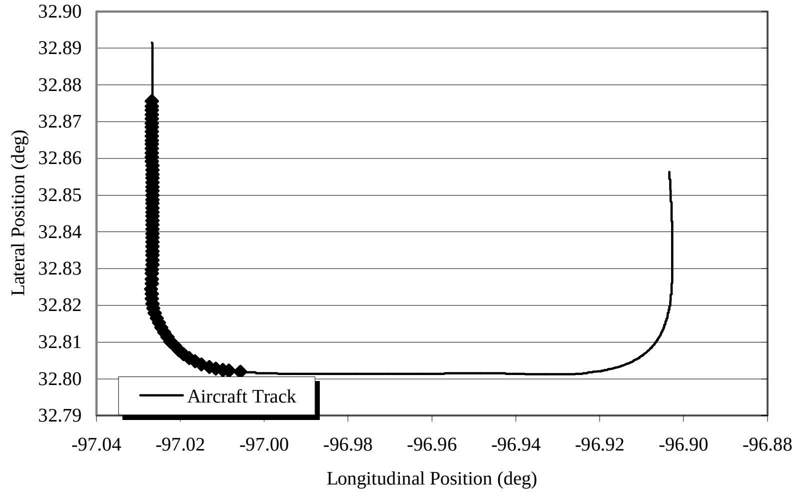
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

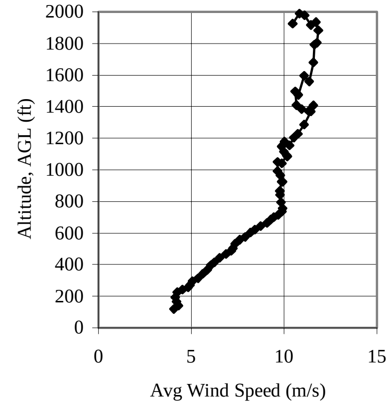
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

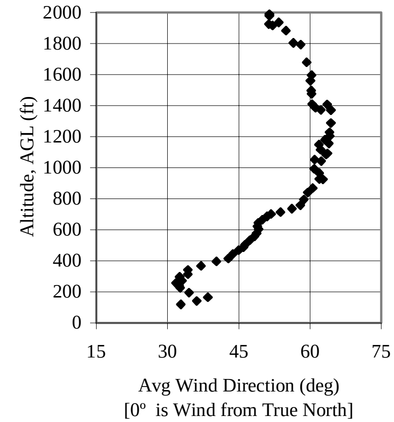
APGATMP = 5s
APGAEDR = 20s

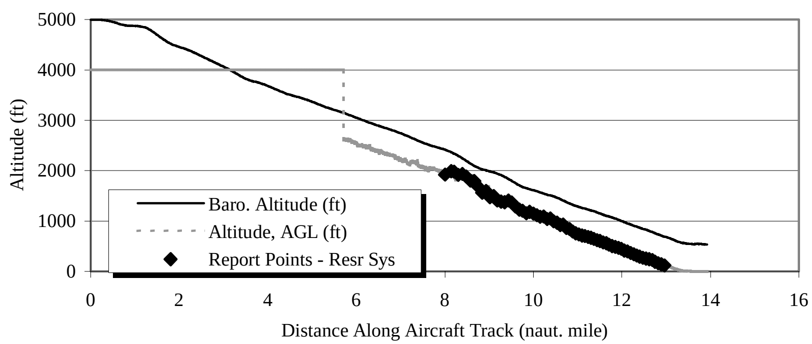
APGAWNS = 5s
APGAWND = 5s

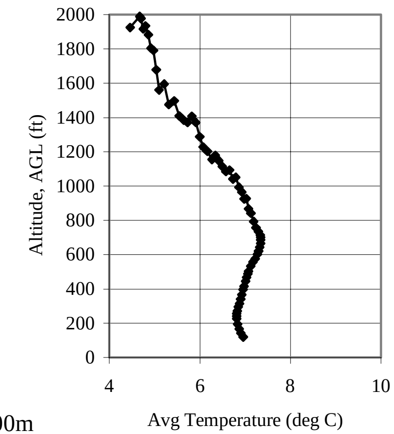
AeroTech Research (U.S.A.), Inc.

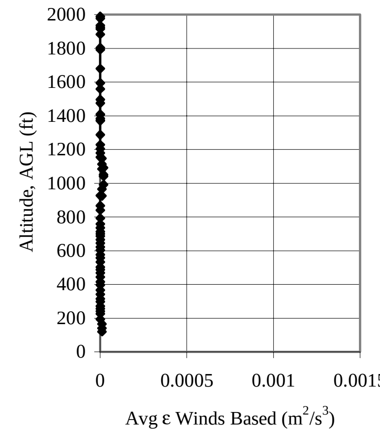












R165 - Run 07

Atmospheric Profile Generation Algorithm

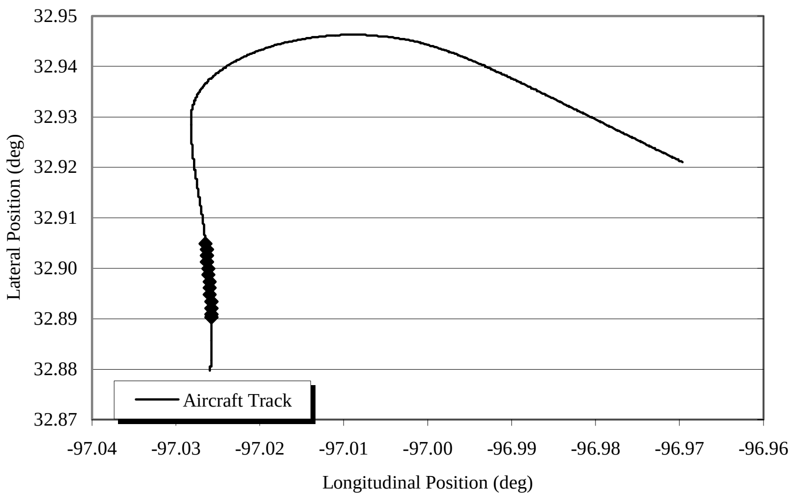
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

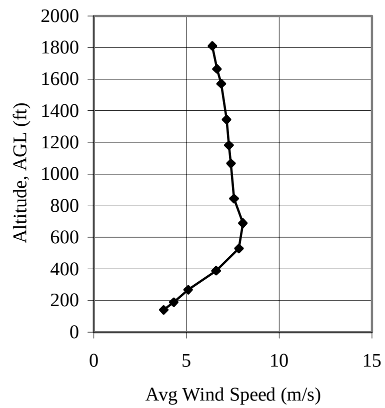
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

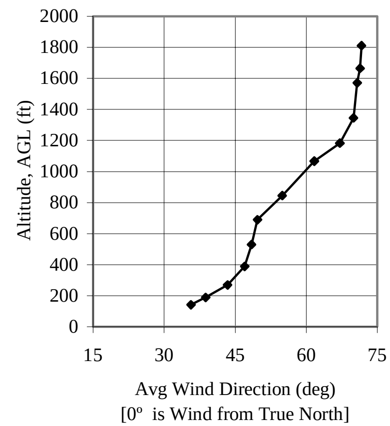
APGATMP = 5s
APGAEDR = 20s

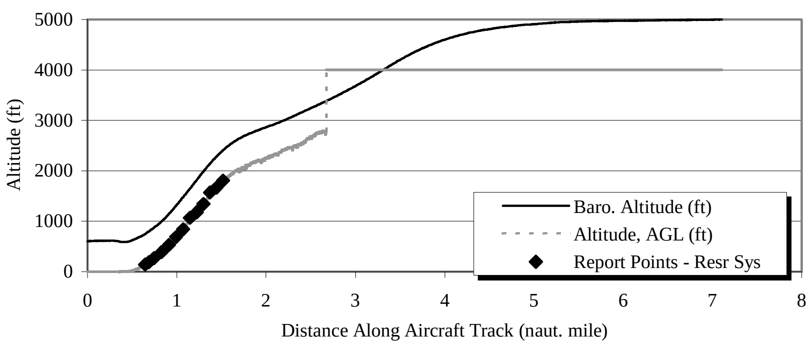
APGAWNS = 5s
APGAWND = 5s

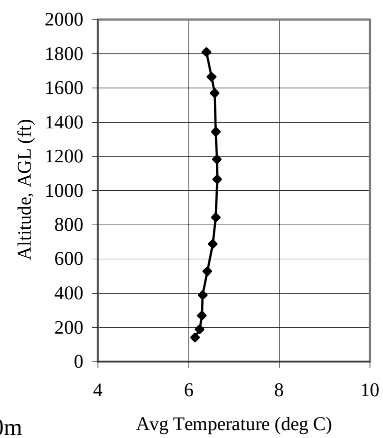
AeroTech Research (U.S.A.), Inc.

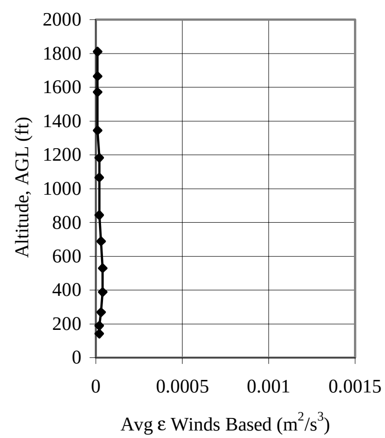










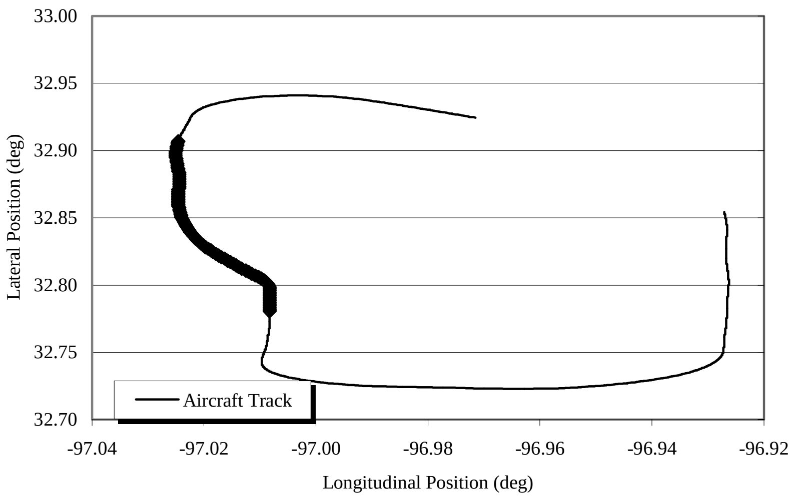


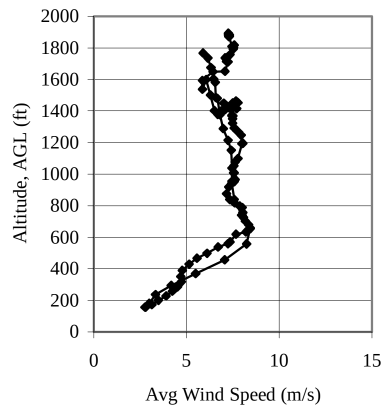
<u>R165 - Run 08</u>
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

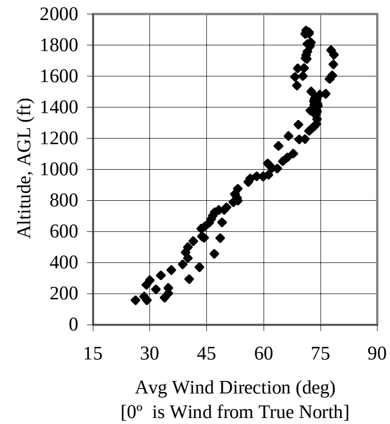
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

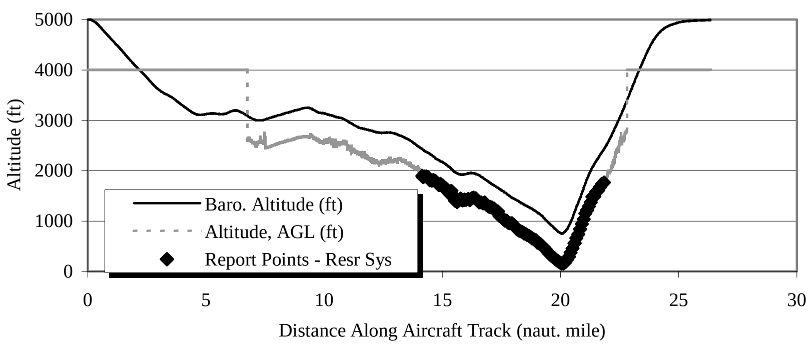
APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

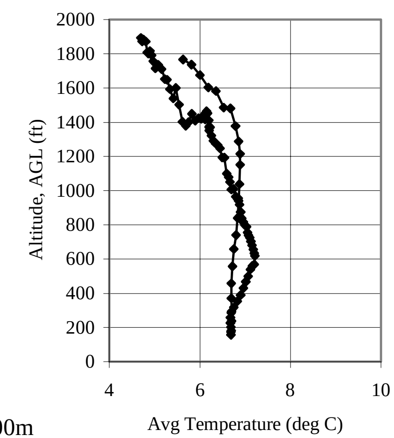
AeroTech Research (U.S.A.), Inc.

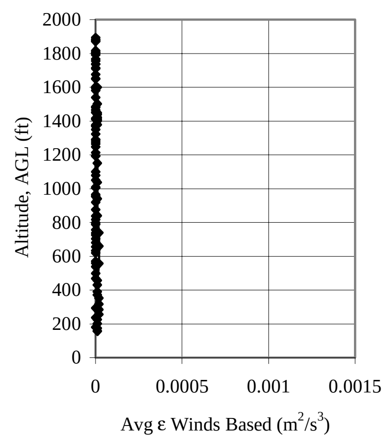












R165 - Run 09

Atmospheric Profile Generation Algorithm

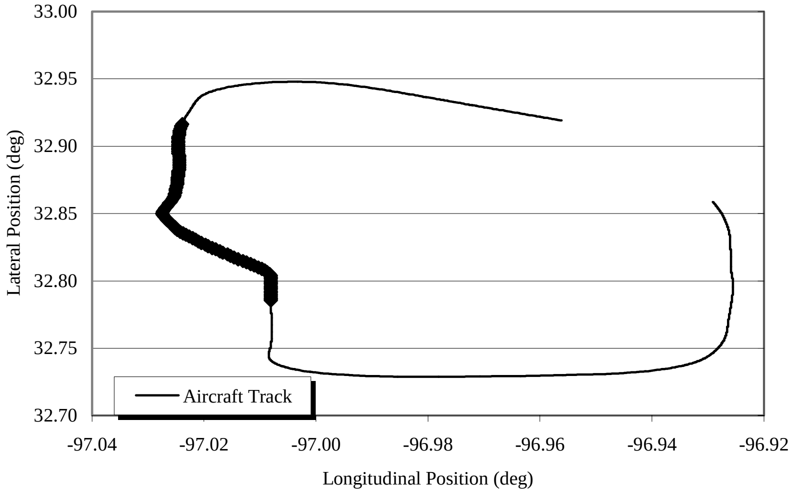
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

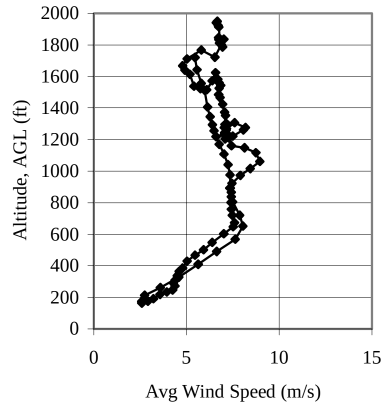
APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

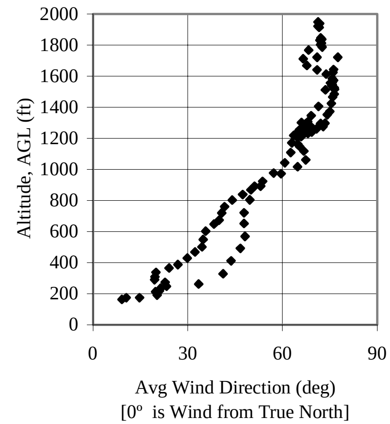
APGATMP = 5s
APGAEDR = 20s

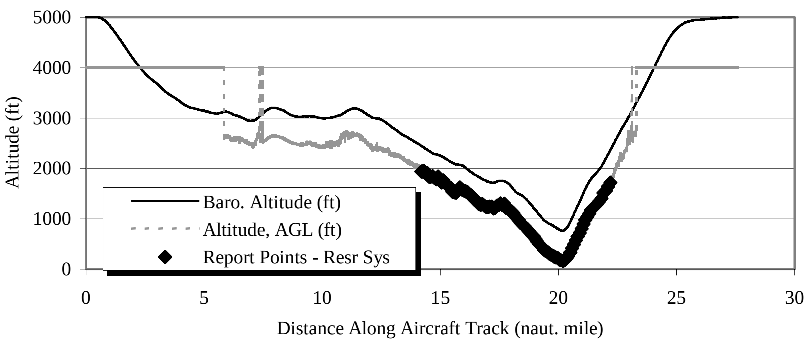
APGAWNS = 5s
APGAWND = 5s

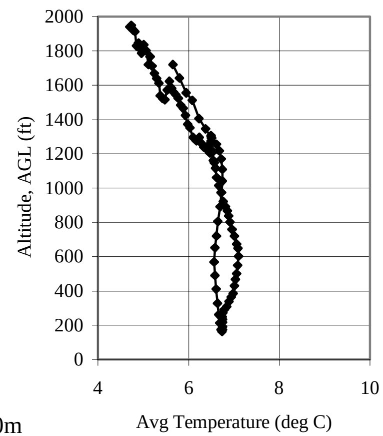
AeroTech Research (U.S.A.), Inc.

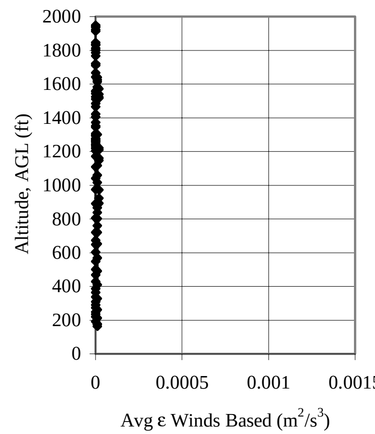












R165 - Run 10
Atmospheric Profile Generation Algorithm
Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

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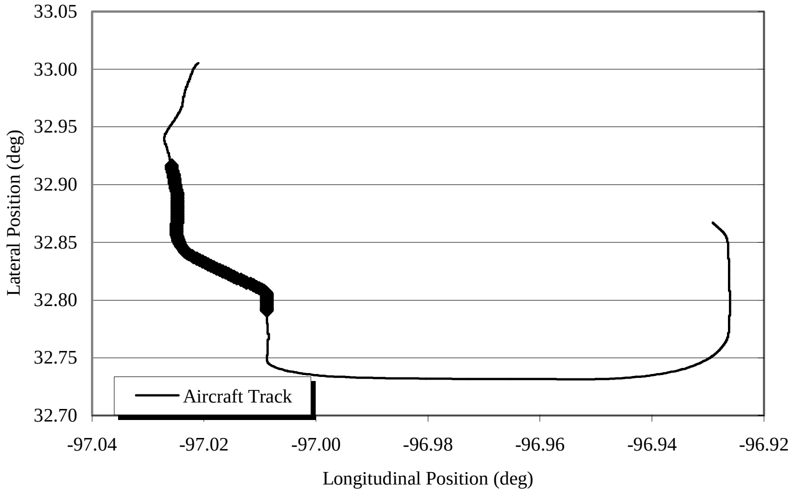

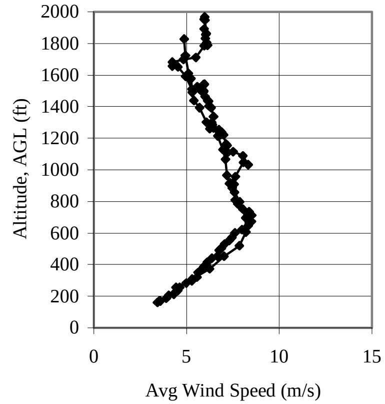

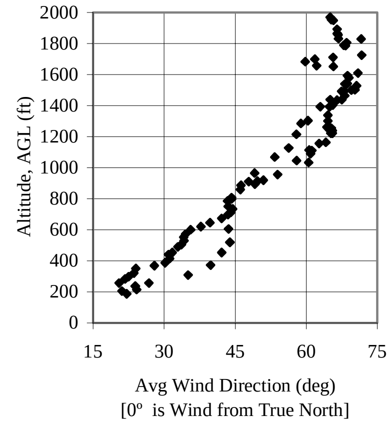

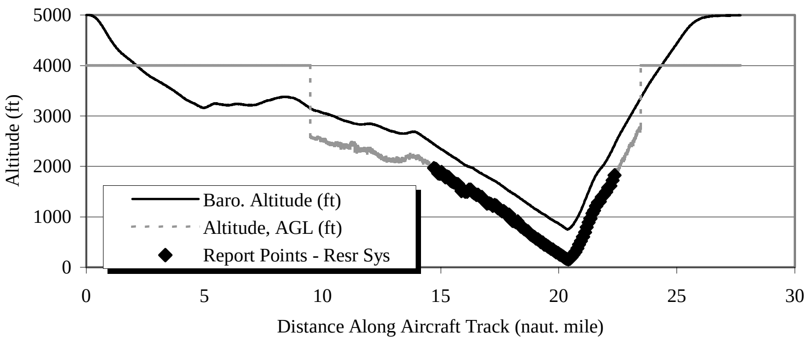

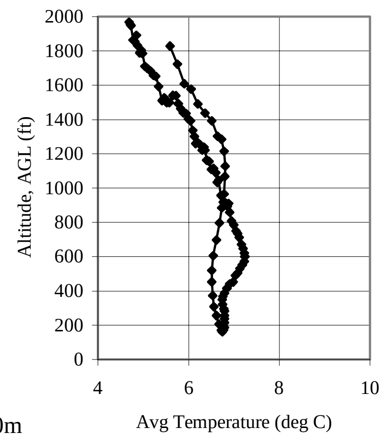

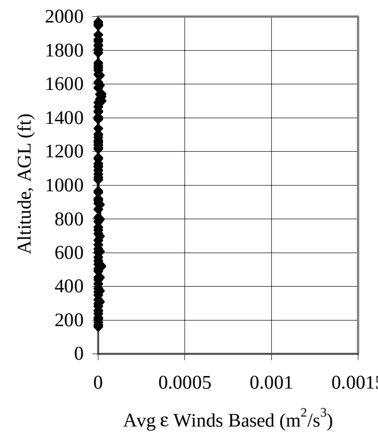

R165 - Run 11

Atmospheric Profile Generation Algorithm

Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

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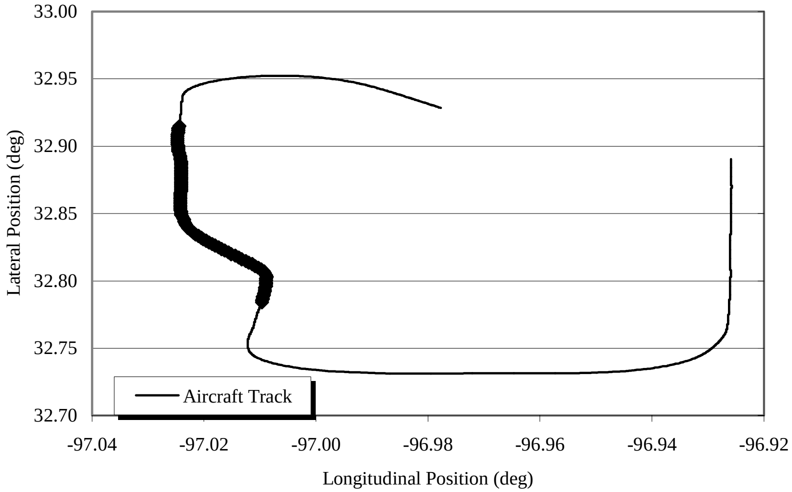

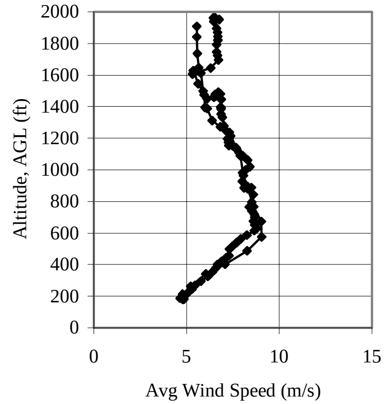

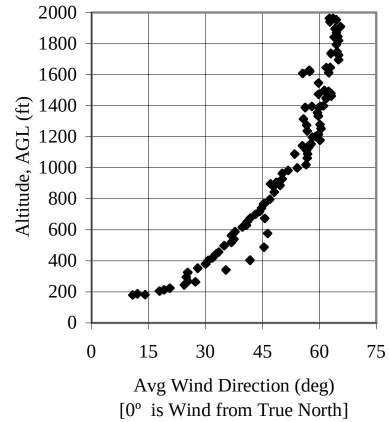

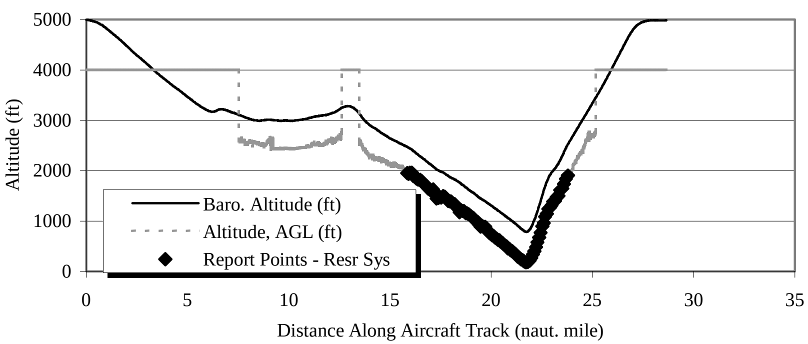

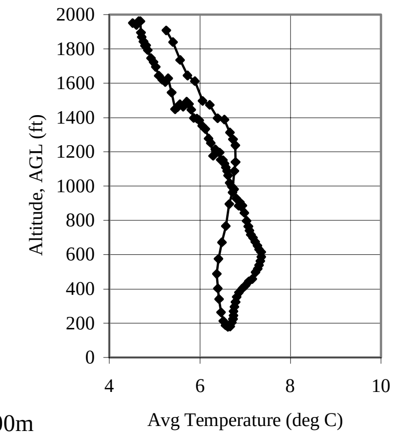

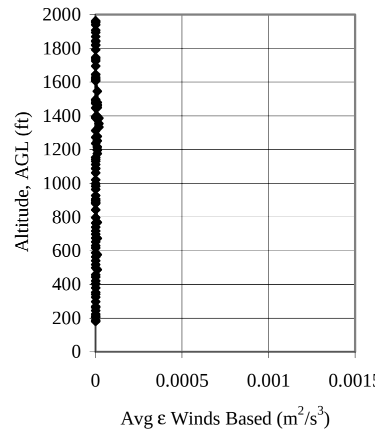

<u>R165 - Run 12</u>

Atmospheric Profile Generation Algorithm

Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

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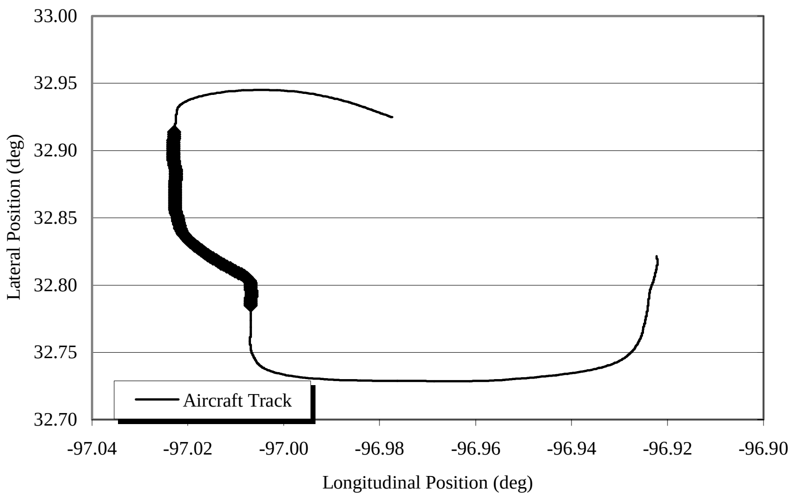

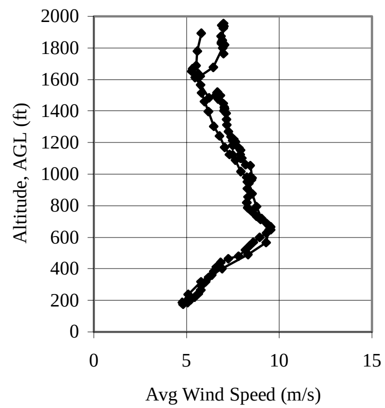

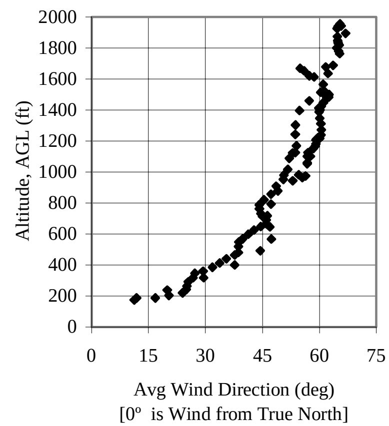

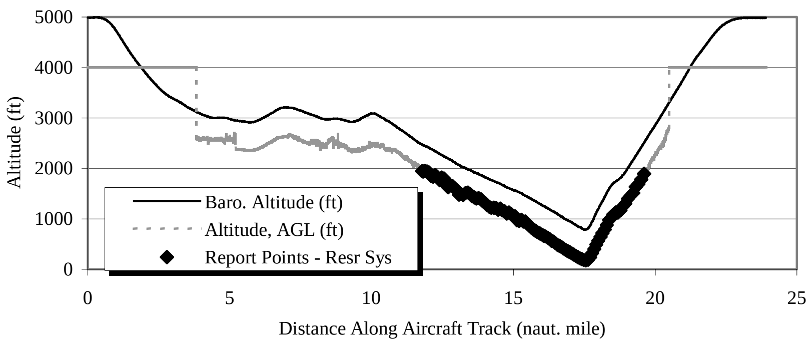

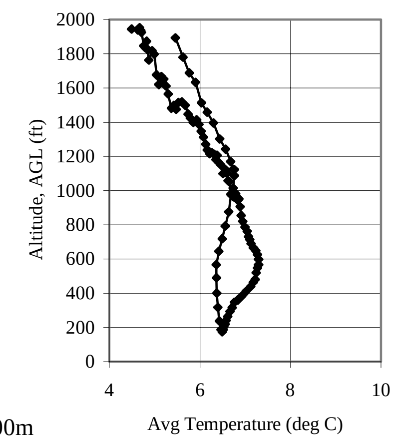

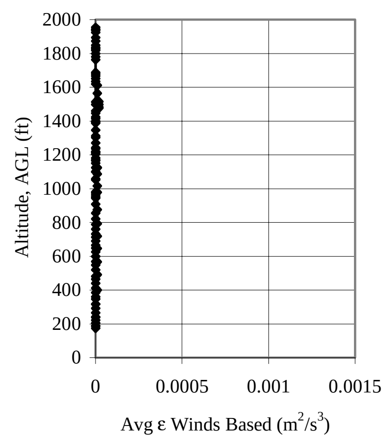

R165 - Run 13

Atmospheric Profile Generation Algorithm

Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s
APGAEDR = 20s

APGAWNS = 5s
APGAWND = 5s

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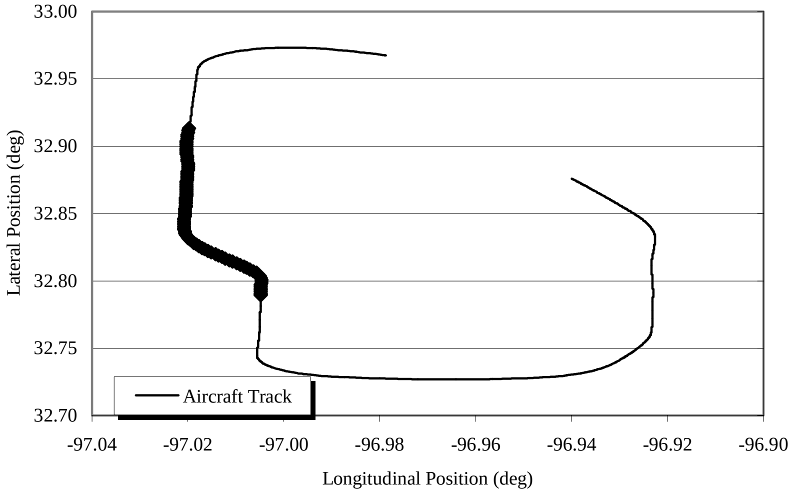

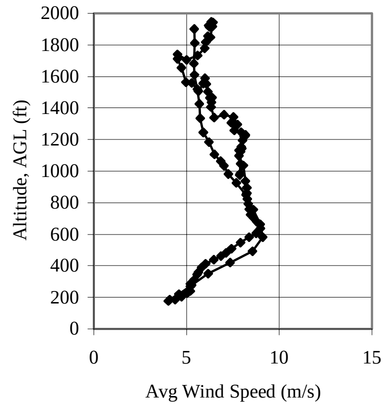

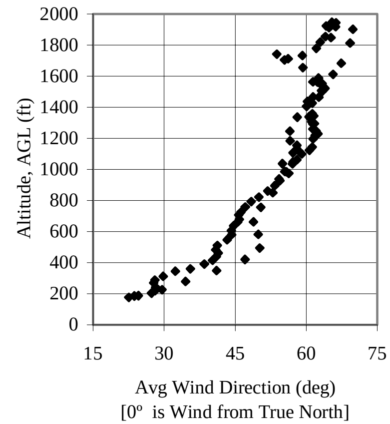

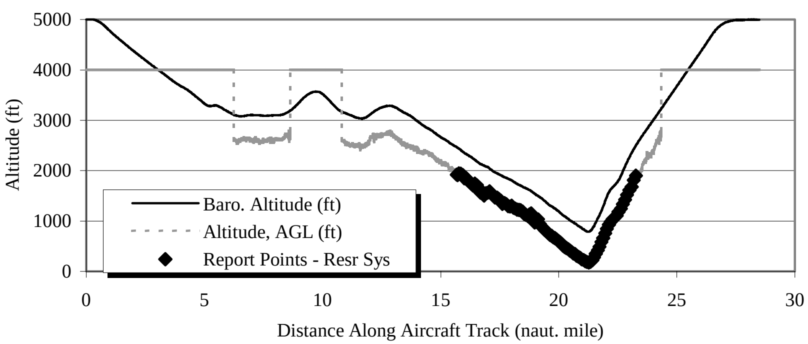

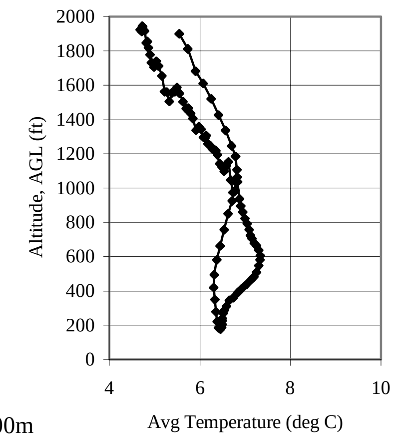

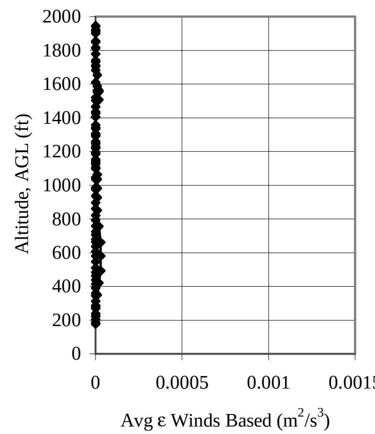

R165 - Run 14

Atmospheric Profile Generation Algorithm

Data Source: NASA B757-200 Test Flights at DFW, Oct. 8, 2000

APGAStart = 3000m
APGALow = 30m
APGAHigh = 600m

APGATMP = 5s APGAWNS = 5s
APGAEDR = 20s APGAWND = 5s

AeroTech Research (U.S.A.), Inc.

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14. ABSTRACT
In support of NASA Virtual Airspace Modeling and Simulation (VAMS) project, an effort was initiated to develop and test techniques for extracting meteorological data from landing and departing aircraft, and for building altitude based profiles for key meteorological parameters from these data. The generated atmospheric profiles will be used as inputs to NASA's Aircraft Vortex Spacing System (AVOLSS) Prediction Algorithm (APA) for benefits and trade analysis. A Wake Vortex Advisory System (WakeVAS) is being developed to apply weather and wake prediction and sensing technologies with procedures to reduce current wake separation criteria when safe and appropriate to increase airport operational efficiency. The purpose of this report is to document the initial theory and design of the Aircraft Approach Departure Atmospheric Profile Generation Algorithm.

15. SUBJECT TERMS
Aircraft spacing; Aircraft wake vortex

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