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ANALYSIS OF USAir FLIGHT 1016

by

Honeywell

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ANALYSIS OF USAir FLIGHT 1016

SUBMITTED TO THE NATIONAL TRANSPORTATION SAFETY BOARD
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A. DESCRIPTION OF EQUIPMENT

USAir Flight 1016 was equipped with Honeywell Windshear Computer P/N 4068048-901, S/N 92030308 which was installed on the aircraft in June of 1993. There are no records of the unit having been removed from the aircraft nor of having been into the shop for repair.

Honeywell received a Supplemental Type Certificate SA4817NM from the Federal Aviation Administration (FAA) for installation of the Windshear Computer on Douglas aircraft on 1 December 1989.

The Windshear Computers installed on USAir's DC-9-30 aircraft are detection only systems; that is, no guidance is provided, either through flight director or autopilot commands, to the flight crew in a windshear encounter.

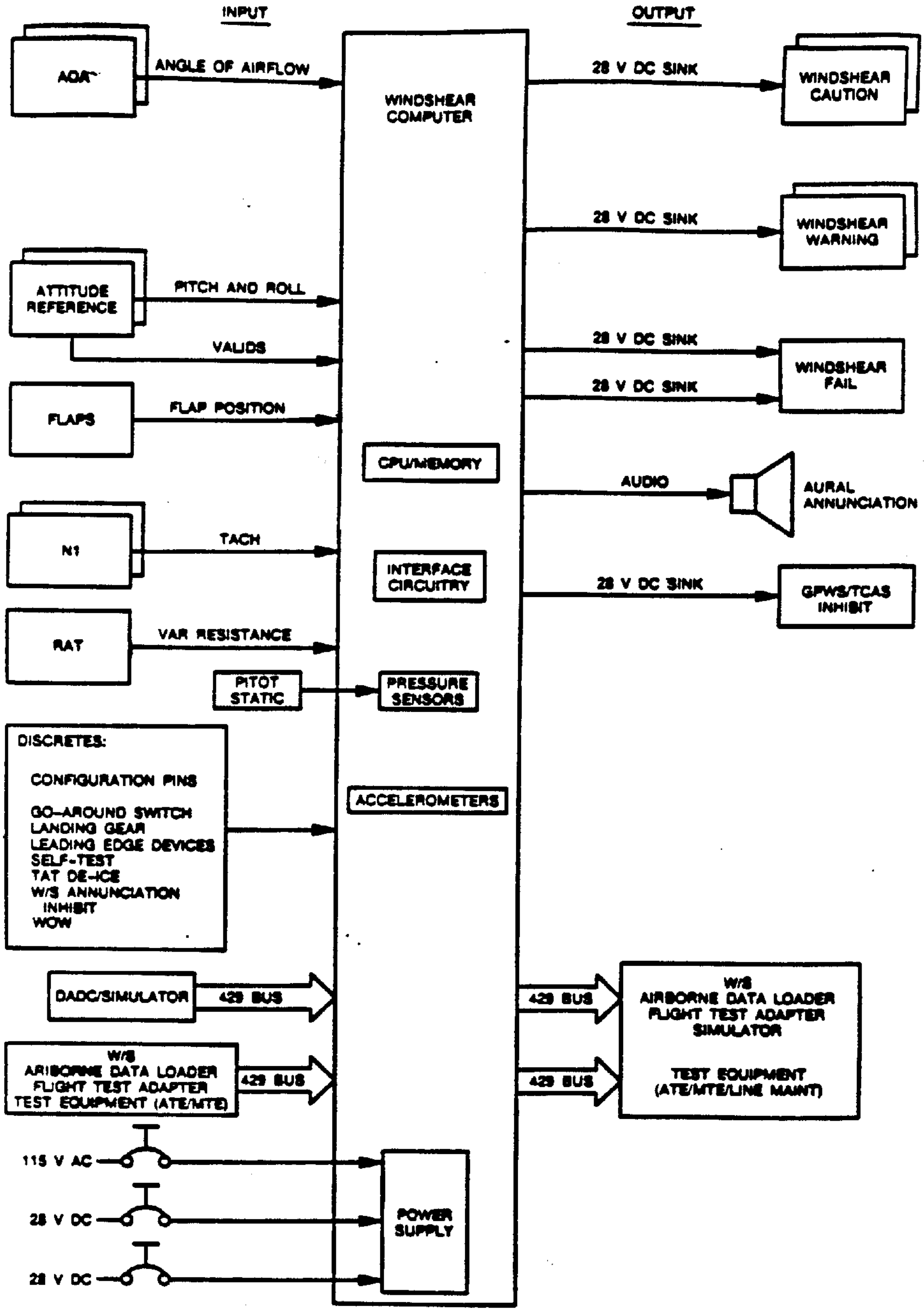
The Windshear Computer detects the presence of a windshear by comparing the aircraft's airmass and inertial accelerations in the longitudinal and vertical axes of the aircraft. A difference between the airmass and inertial accelerations is a direct measurement of a shear. Windshear detection is active for both positive and negative shears in the longitudinal and vertical axis. The alerting of the fight crew of the presence of a windshear is dependent on the magnitude and duration of the encountered shear.

When the magnitude and duration of a shear has reduced the aircraft's total energy by a predetermined amount, a warning alert is issued to the flight crew via flashing red lights on both the Captain's and First Officer's glareshields accompanied by an aural annunciation of the word "Windshear" repeated three times. In the event that a shear has increased the energy of the aircraft, a caution warning is given by flashing amber lights in the cockpit -- no aural annunciation occurs.

The Windshear Computer also measures the change of temperature with altitude (lapse rate) in the landing approach phase of flight. If the lapse rate is initially dry adiabatic, indicating an unstable airmass, followed by a lower than normal lapse rate (indicating a cold outflow) the windshear caution light in the cockpit is illuminated but not flashed. If a dry adiabatic lapse rate is present, the sensitivities of the windshear detection thresholds are adjusted. Since it is currently unknown if a dry adiabatic lapse occurred on the approach of Flight 1016, no credit was taken in this analysis for this feature.

The Windshear Computer has its own self-contained accelerometers and air data functions, but is dependent on other sensors on the aircraft, including the aircraft's attitude reference, ram air temperature probe, engine tachometers (N1), angle of attack vanes, and flap position. It also receives discrete signals from the go-around switches, landing gear, leading edge devices, and weight-on-wheels sensor. A functional block diagram of the system for DC-9-30 aircraft is shown on Figure A.

The Windshear Computer also contains Built-In-Test-Equipment that monitors the performance of the internal computations of the system and the performance of external and internal sensors. A detected failure of internal hardware or software or an input sensor



DC-9-30 WSC Functional Interface Block Diagram

FIGURE A

that is required for proper operation of the system is annunciated to the flight crew via a light in the overhead instrument panel, labeled W/S INOP.

In addition, the Windshear Computer contains non-volatile memory in which any detected system failures occurring in the past 96 flights are logged . The memory also stores any windshear detections that have occurred and the number of times the windshear detection parameters have been above 50% and 75% of the detection thresholds.

Windshear detection is provided in Takeoff, Approach, and Go Around configurations. Using the data from the Flight Data Recorder, windshear detection would have become active during the landing approach at approximately 2200 feet above the ground.

B. RECOVERY OF THE EQUIPMENT

Because of the usefulness of the non-volatile memory in logging failures and detections, Honeywell personnel attempted on 15 August 1994 to recover the Windshear Computer hardware (specifically the printed wiring board that contains the non-volatile memory chips) at Laurenberg, North Carolina, the wreckage storage site. Accompanying the Honeywell personnel were representatives from the NTSB, the FAA, USAir, and the Airline Pilots Association (ALPA).

This recovery effort was unsuccessful in recovering the card which houses the non-volatile memory. Some parts of the hardware were found including an Input/Output interface card, the computer mother board, and the accelerometer interface card. Remnants were also found of the Pitot/Static tubing interface.

None of the recovered hardware was helpful in this analysis.

C. ANALYSIS OF DATA FROM THE FLIGHT DATA RECORDER

Data from the Flight Data Recorder (FDR) was analyzed by two methods. The first consisted of inputting the data into an emulation of the Windshear Computer detection algorithms to determine if (a) an actual windshear occurred, and (b) if a windshear did occur, why no recording of the windshear aural annunciation was present on the Cockpit Voice Recorder, as reported by the NTSB.

The second method involved the use of a six-degree-of-freedom engineering simulator of the DC-9-30 aircraft. This method utilized the pitch, roll and engine pressure ratio (EPR) data from the FDR to simulate the last 40 seconds of Flight 1016.

D. ALGORITHM EMULATION

Data from the FDR were used to drive a computer emulation of the actual algorithms used in the Windshear Computer.

While the Windshear Computer calculates windshear detection parameters 15.25 times per second, data from the FDR is recorded at slower rates. Specifically, airspeed, which is a critical parameter in the detection algorithms, is recorded once per second. Consequently, all data from the FDR was analyzed using a once-per-second sampling rate.

Angle of attack, another critical parameter in the detection of vertical windshears, is not recorded by the FDR. Therefore, it was necessary to derive angle of attack data. This was done using two independent methods: (a) computing airmass flight path angle (gamma) by subtracting the ratio of the aircraft's altitude rate and true airspeed from the aircraft's pitch angle, and (b) using data supplied by McDonnell-Douglas to compute the angle of attack for zero lift and using the computation in an algorithm that derives angle of attack from true airspeeds and normal accelerations.

It was known that method (a) above is generally inaccurate in presence of downdrafts and updrafts, but was useful in determining angle of attack at points along the flight path not thought to have these phenomena.

Method (b) has been successfully tested by Honeywell in numerous actual flights of a DC-9-50 aircraft where actual angle of attack could be compared to the computed value, and it was used for the bulk of this analysis. It also showed good agreement with data from the subsequent simulator runs.

Using the methods described above and correcting FDR accelerometer data for the location of the Windshear Computer in the aircraft, it was possible to determine if a windshear condition did exist on Flight 1016 and whether or not the Windshear Computer would have detected it. It was also possible to derive the magnitudes of the winds encountered.

The emulation showed that windshears were indeed present during the last portion of Flight 1016. It also showed that a windshear warning, accompanied by an aural annunciation, should have occurred.

E. DERIVATION OF WINDS

As mentioned above, the encountered winds could be derived from data available on the FDR coupled with a computation of angle of attack.

The derivation showed a differential longitudinal wind change of approximately 60 knots over a 13 second period, for an average shear of 4.6 knots per second. This result is in good agreement with that done with a different methodology by James Ritter of the NTSB. His results indicated the presence of a 4 knot per second shear.

Initial derivation of vertical winds was not as successful. For validation, two methods were used. One method involved the use of pitch attitude, derived angle of attack and true airspeed; the second method utilized the second derivative of recorded altitude. Both methods compute the aircraft's acceleration relative to the airmass. By subtracting the airmass accelerations from the aircraft's inertial vertical acceleration, supplied by the FDR normal accelerometer, a measurement of vertical wind rate is obtained. Integrating this result should produce the vertical wind.

The results indicated implausibly high vertical winds near the ground -- of the order of 55 knots. Further investigation revealed that the FDR normal accelerometer had an error bias. Since both methodologies discussed above used the normal accelerometer for the determination of vertical wind rate, the error was present in both. The effect of the bias on the normal accelerometer was to produce a relatively large error in derived wind due to mathematical integration. Subsequent aircraft simulator tests indicated that the bias was of the order of -0.065 g. FDR data during the time the aircraft was on the ground prior to takeoff at Columbia, South Carolina, produced an average accelerometer bias of -0.045 g. An independent NTSB analysis resulted in a bias determination of -0.0535 g.

F. AIRCRAFT SIMULATOR ANALYSIS

Simulation runs were made on a Honeywell six-degree-of-freedom engineering simulator for the DC-9-30 series aircraft. The simulator, called a Development Integration and Test Station (DITS), has been used during Windshear Computer certifications and was conformed by the FAA in February, 1993, with conformity tag number NM100L-2063. The DITS uses aerodynamic data provided by the aircraft manufacturer in the aircraft's equations of motion to simulate actual aircraft response. Verification of the simulation was performed for the FAA per their approved procedures.

The data from the simulation was used as inputs to a DC-9-30 Windshear Computer, P/N 4068048-901, S/N 90020434.

The DITS was configured with aircraft parameters supplied by the NTSB:

Gross Weight:	82,225 pounds
C.G. Location:	25.3% Mean Aerodynamic Chord
Engine Type:	Pratt & Whitney JT8D-7
Glide Slope Angle:	2.96 degrees
Initial Flap Pos.:	40 degrees
Gear Position:	Down
Surface Temperature:	77 Degrees Fahrenheit

The simulation was run using three control parameters derived from the FDR data: pitch attitude, roll attitude, and engine pressure ratio. Flaps were retracted from 40 to 15 degrees approximately 15 seconds prior to the end of the flight, conforming to data supplied by the NTSB.

As can be seen from the accompanying figures, the simulator's pitch angle and engine pressure ratio tracked the actual data reasonably well. Roll angle tended to lag actual roll angle somewhat due to the response time of the DITS simulated autopilot.

Runs were done both with and without derived winds. In the no wind case, the altitude and airspeed data from the simulation differed significantly from the actual FDR data. The simulated aircraft's pressure altitude never decreased below 900 feet, and indicated airspeed continuously increased after execution of the go-around maneuver. Since vertical and longitudinal windshear directly affects these two parameters, these results were not unexpected. Data from this run are shown on Figures 1 to 10 inclusive.

A simulator run using the derived winds (see section E above) resulted in airspeed and altitude data that was drastically different from actual. In this case, the aircraft impacted the ground approximately 22 seconds before the actual time.

As mentioned in section E, the bias on the normal accelerometer produced large errors in the computation of vertical wind. The vertical wind necessary to duplicate the FDR data was empirically determined by reducing the wind by a multiplying factor of 0.225. With this factor, the simulator matched the actual airspeed and altitude data quite well, with ground impact occurring within a second of actual. (No attempt was made to alter the derived longitudinal winds since the derivation agreed well with NTSB results.)

Data for the run with derived winds are shown on figures 11 to 22 inclusive.

One difference noted during the simulator tests was that stick shaker was not activated during the entire run. Data supplied by the NTSB showed stick shaker activation during the final seconds of the flight. The peak angle of attack seen in the derived winds case was 13.3 degrees (relative to the fuselage reference line, FRL). Assuming the flaps had retracted to 15 degrees at this time (simulator data shows that to be the case), the stick shaker angle of attack should have been 18.6 degrees. Even accounting for the angle of attack rate term that is used in the stick shaker activation system which has the potential to reduce the angle of attack for activation by approximately 2.5 degrees (effective stick shaker angle of 16.1 deg.), no stick shaker activation would have occurred. However, it should be noted that the DITS simulator does not include a simulation of the effects of very heavy rain, which to date are not well understood, and it is conceivable that this may have played a factor.

G. WINDSHEAR DETECTION

Both the algorithm emulation data and DITS simulator data produced a windshear warning that occurred after the initiation of the go-around maneuver. Agreement for the time of detection between the two methods was within 1 second with the detection occurring at between 150 and 100 feet actual altitude.

It should be noted that the longitudinal shear did not occur until after the execution of the go-around maneuver. It began approximately when the engine pressure ratios had achieved 1.8. The pitch attitude was about 13.5 degrees and the roll attitude was 15.5 degrees. The flaps were in the process of retracting from 40 to 15 degrees.

It is not clear as to why no windshear warning occurred on Flight 1016 when both the algorithm emulation analysis and simulator runs resulted in one. The most likely scenario would be a failure of an input sensor, or possibly a miscompare between two dual sensors, as for example, the angle of attack vanes in very heavy rain. However, without recovery of the nonvolatile memory which logs such failures, any conclusion would be speculative.

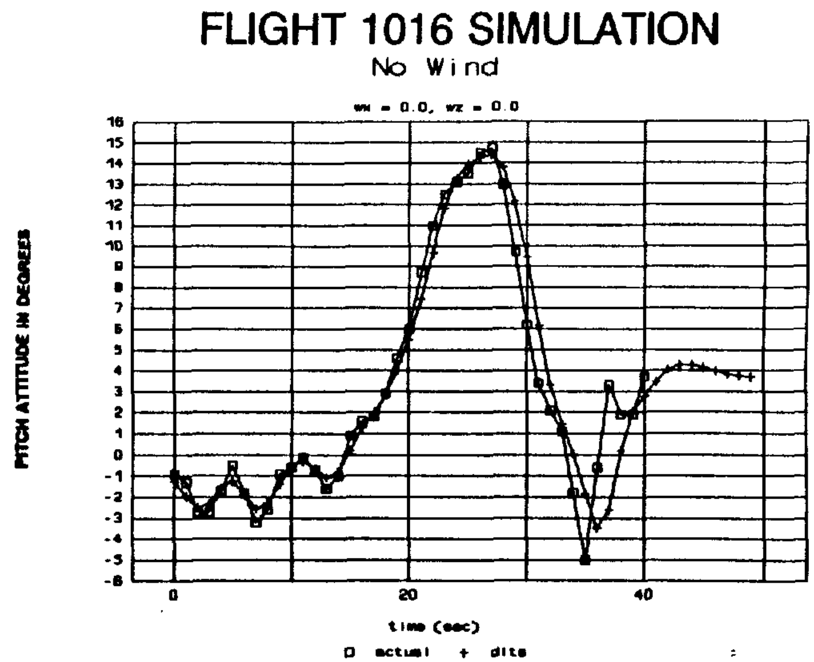


FIGURE 1

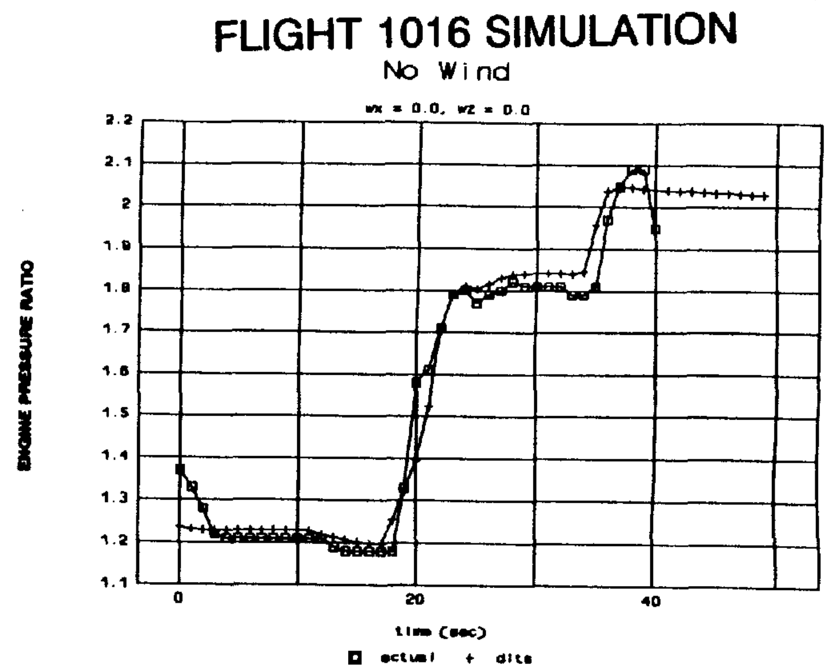


FIGURE 2

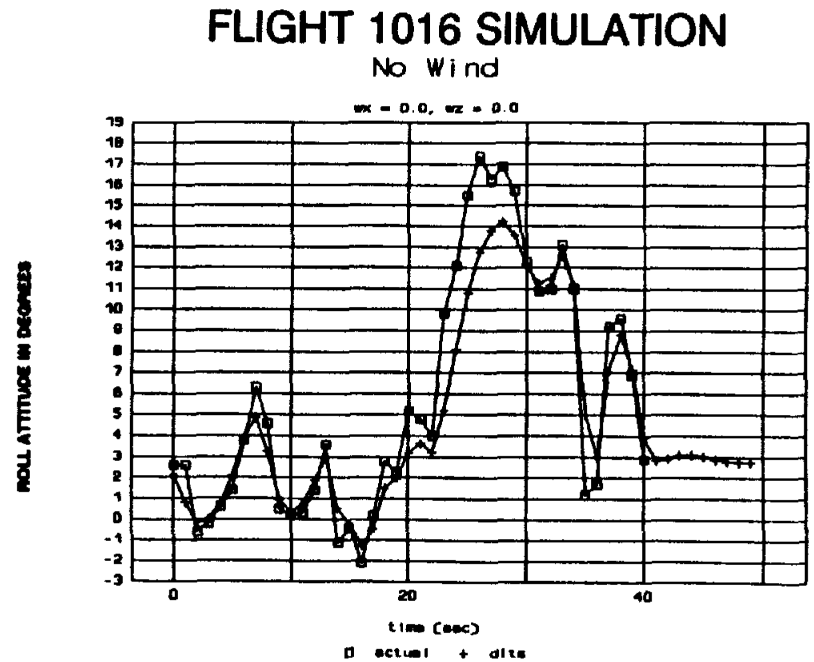


FIGURE 3

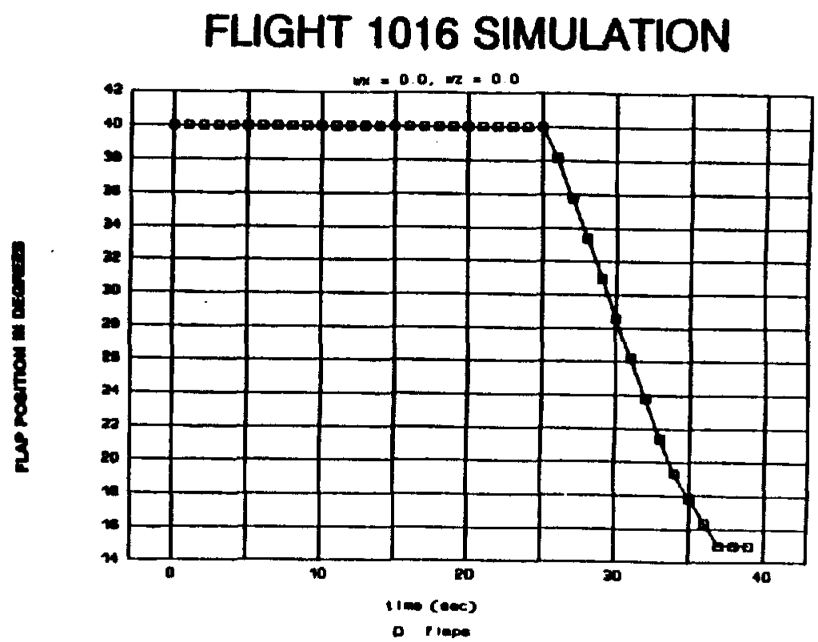


FIGURE 4

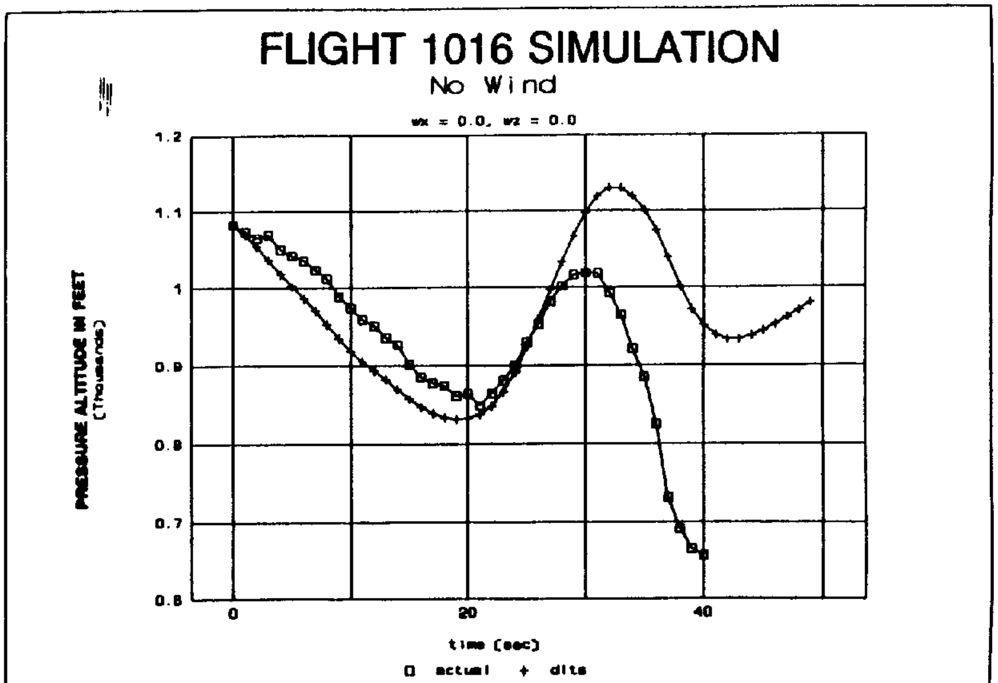


FIGURE 5

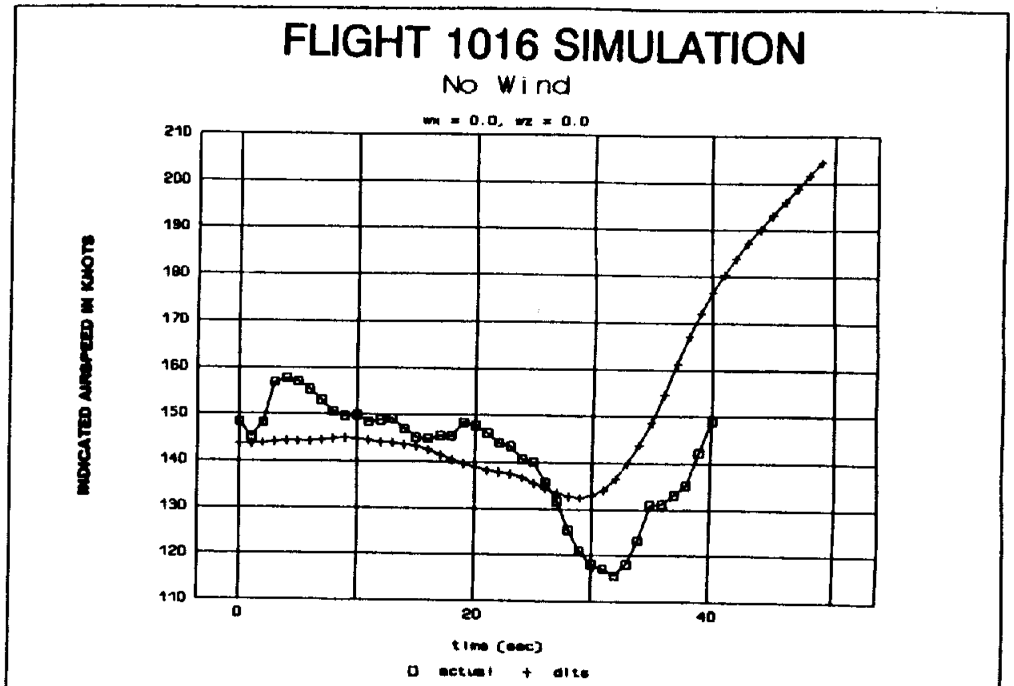
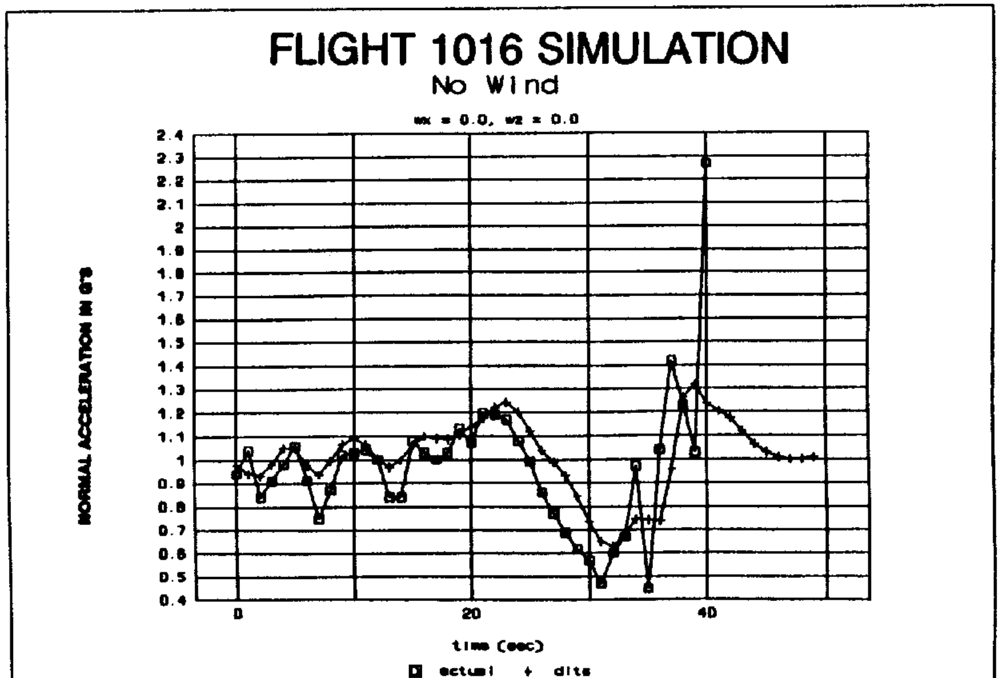


FIGURE 6



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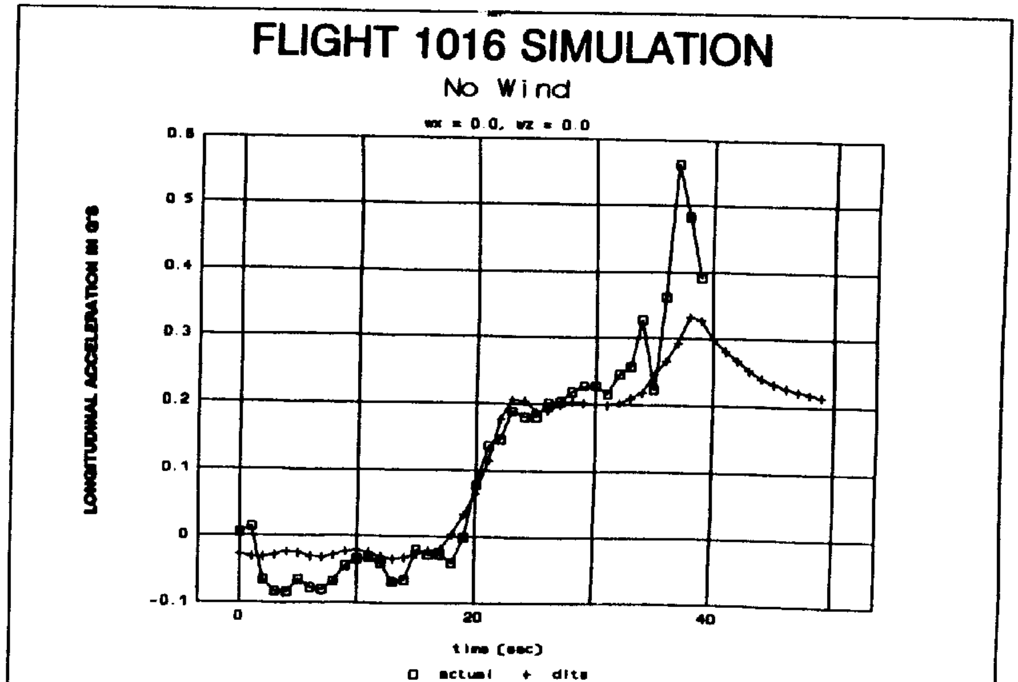
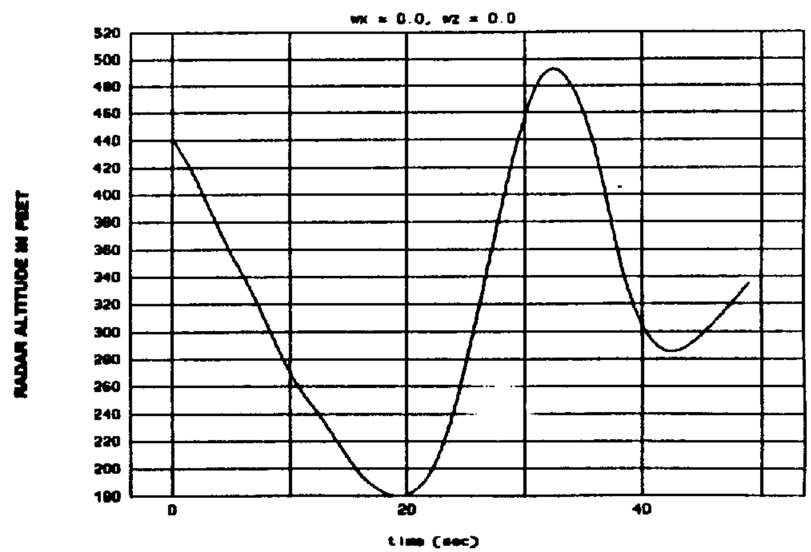


FIGURE 8

FLIGHT 1016 SIMULATION

No Wind

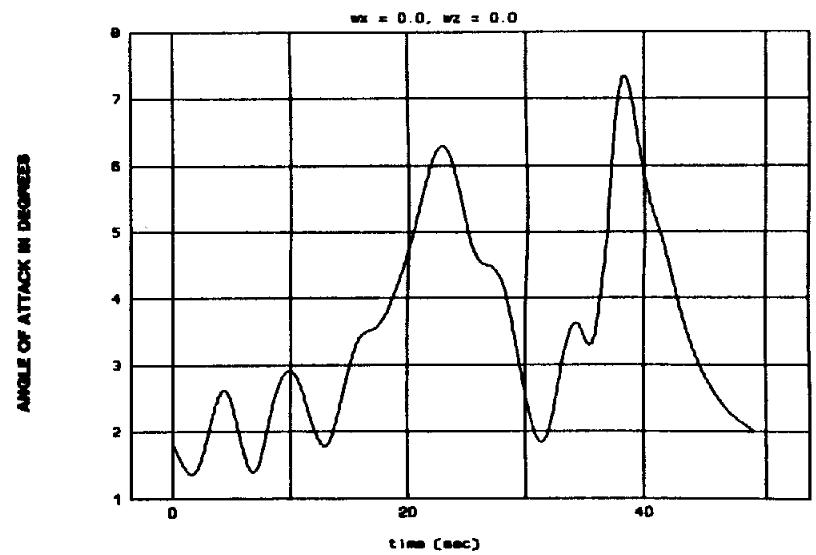


DITS DATA

FIGURE 9

FLIGHT 1016 SIMULATION

No Wind



DITS DATA

FIGURE 10

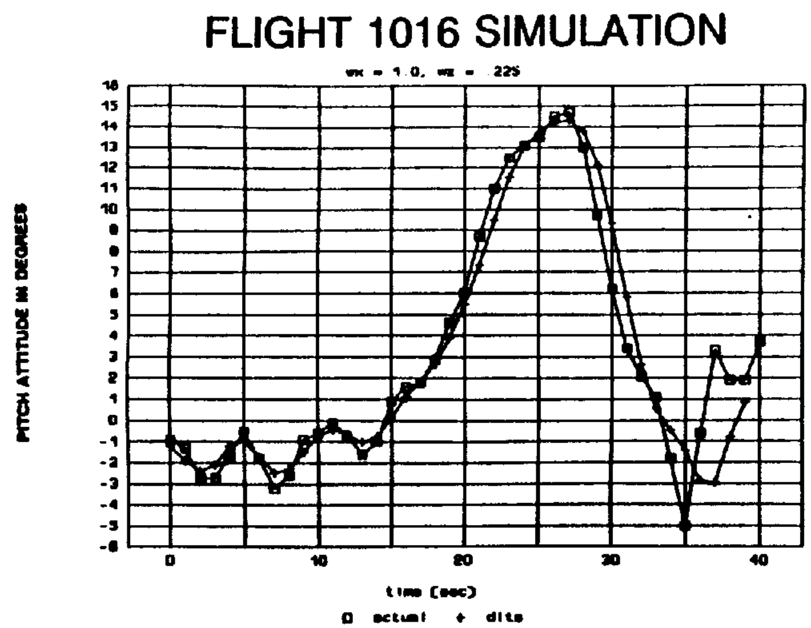


FIGURE 11

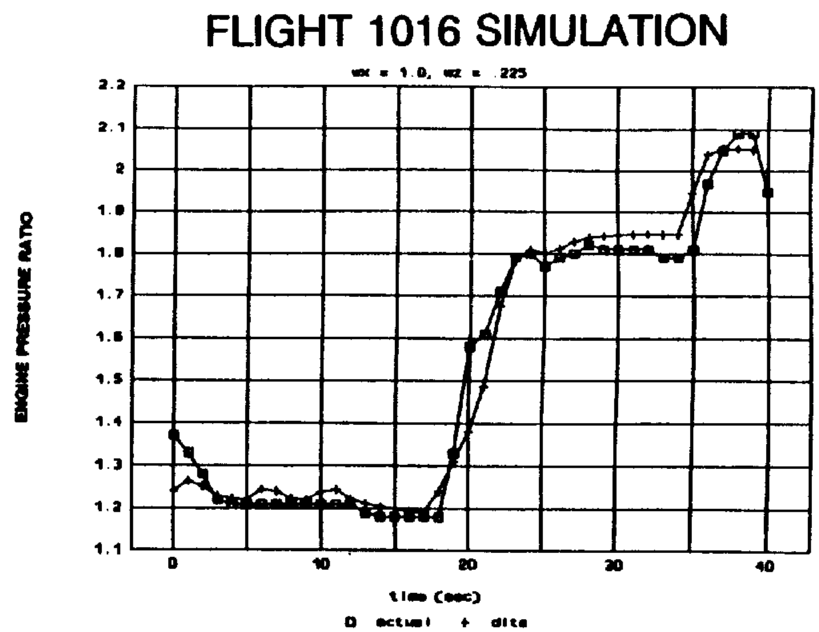


FIGURE 12

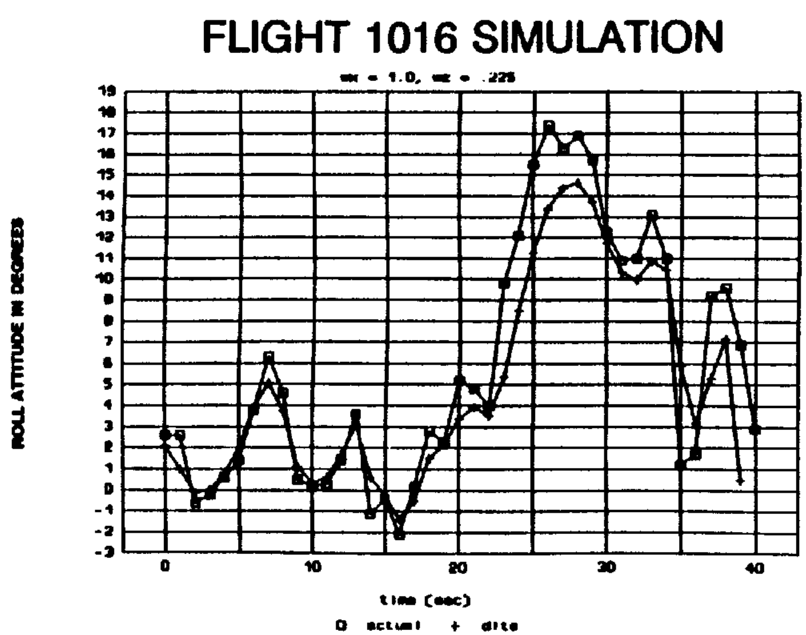


FIGURE 13

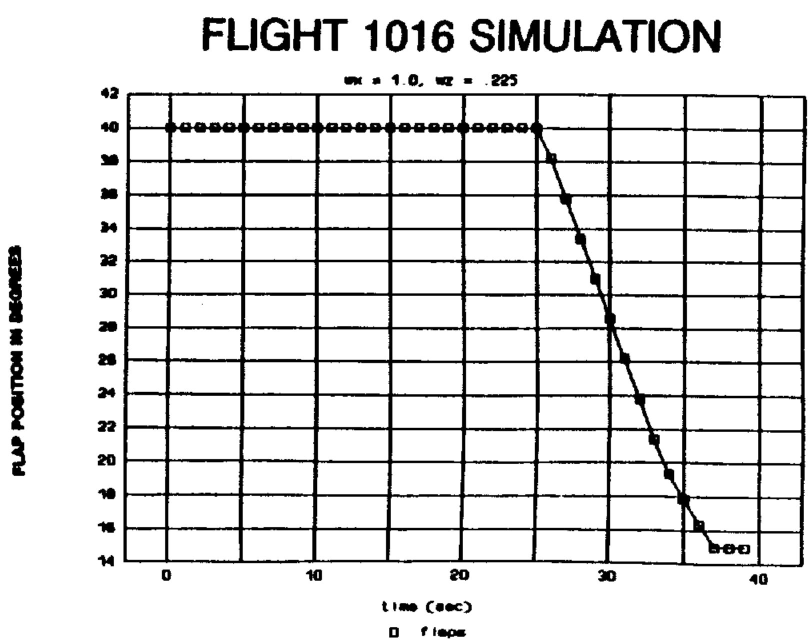


FIGURE 14

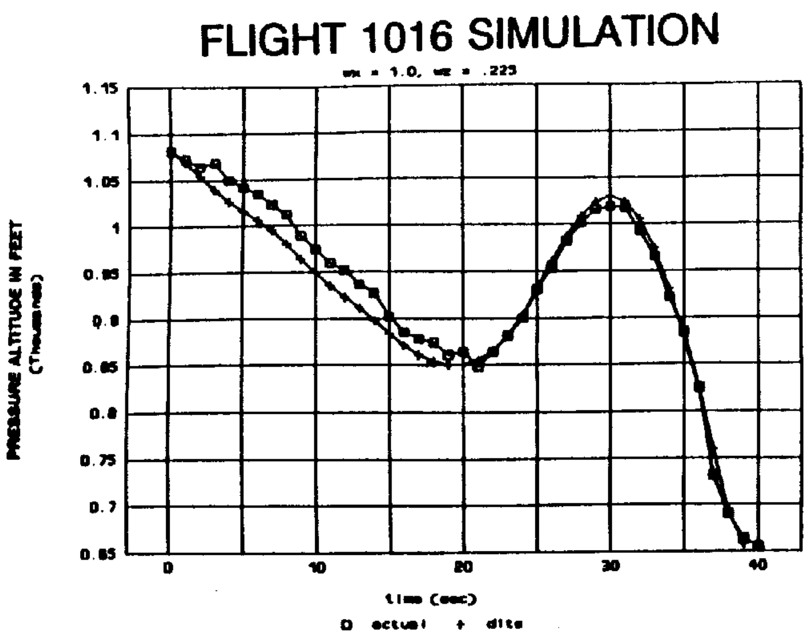


FIGURE 15

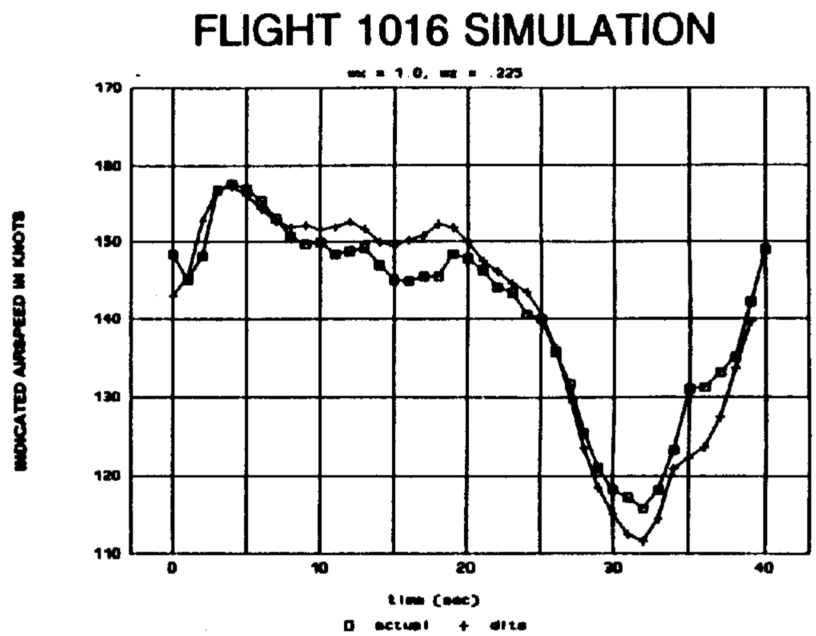


FIGURE 16

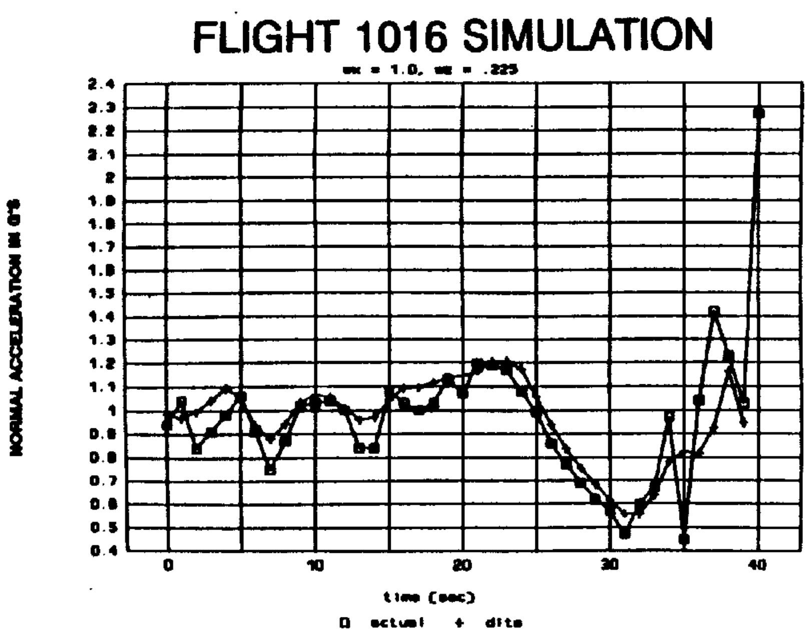
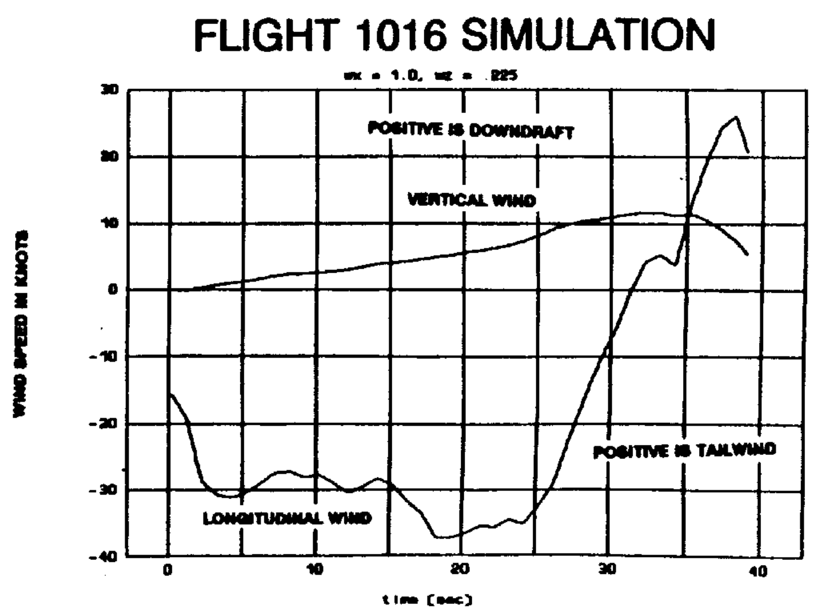
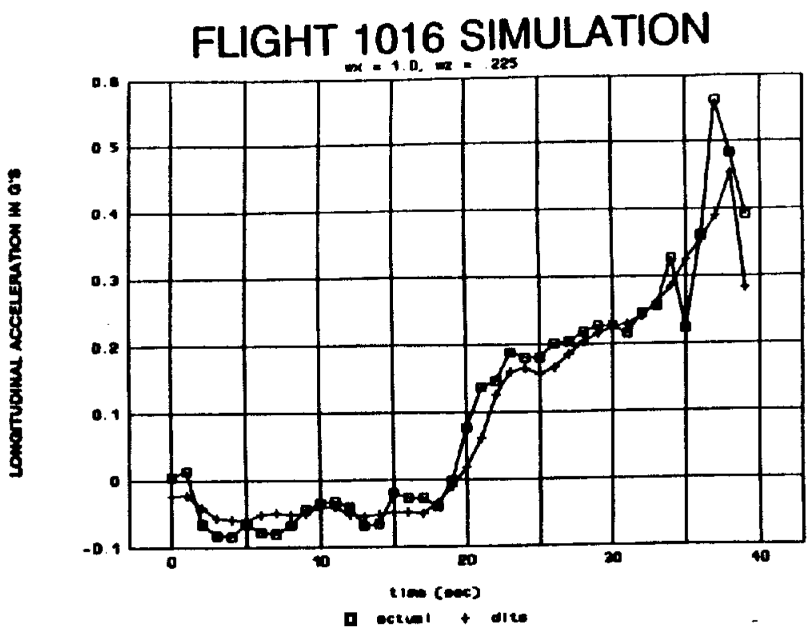


FIGURE 17



DERIVED WINDS

FIGURE 18



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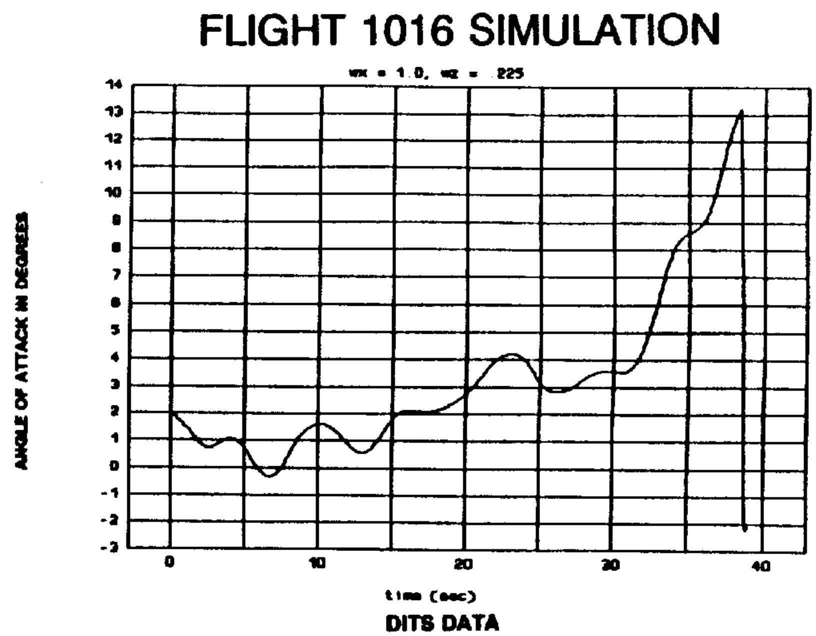

FIGURE 20

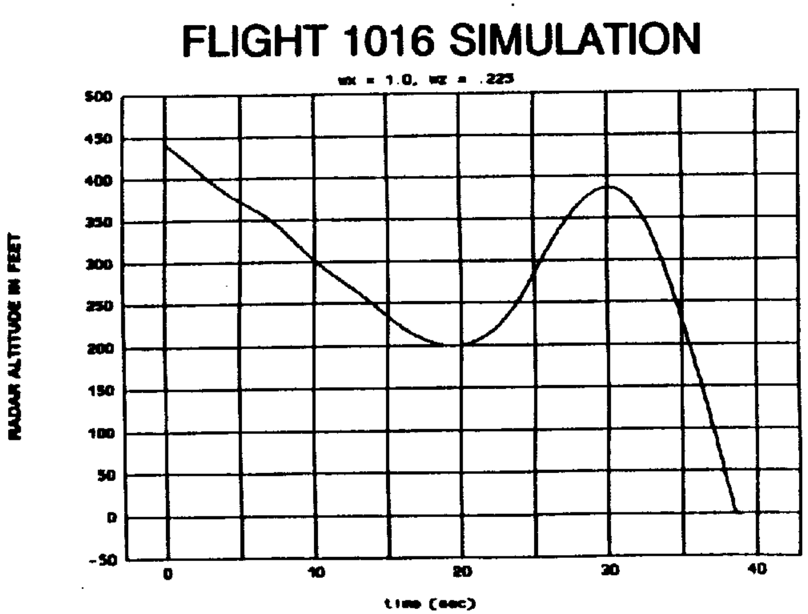

FIGURE 21

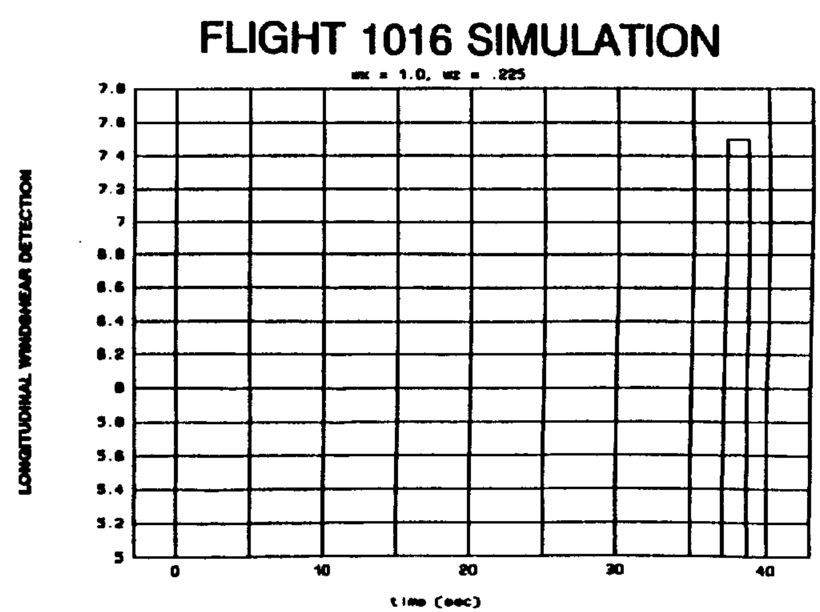

FIGURE 22