Wind Profile Estimation Using a TIDGET™ Payload on Weather Balloons

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BIOGRAPHIES

Amir Matini
Amir Matini is a member of the NAVSYS technical staff. His responsibilities include design and development of antenna, RF, and microwave systems for GPS applications. He is also responsible for the resolution of electromagnetic compatibility and electromagnetic interference problems. Mr. Matini received his BSEE and MSEE degrees from the University of Colorado at Colorado Springs and is continuing studies towards a PhD. His research interests include electromagnetic thermography, antennas, RF and microwave circuits.

Alison Brown
Alison Brown is the President of NAVSYS Corporation, which specializes in developing GPS customized products and services. Dr. Brown has over 15 years experience in GPS receiver design and has seven GPS related patents. She has published numerous papers on GPS applications and is on the editorial board for *GPS World* and *GIS World* magazines. She is currently on the ION Council and is a member of the USAF Scientific Advisory Board. Dr. Brown received her BA and MA in Engineering from Cambridge University, an MS from MIT, and a PhD from UCLA.

James LaMance
James LaMance is a Senior Engineer at NAVSYS Corporation, where he is involved with GPS navigation systems design and analysis. Dr. LaMance has worked in the areas of GPS, remote sensing, and orbit determination for the past six years. Dr. LaMance holds a PhD and MS in Aerospace Engineering from the University of Colorado at Boulder, and a BS in Aerospace Engineering from Auburn University, Auburn, AL.

ABSTRACT

Wind profile data is collected at ranges prior to the launch of high dynamic vehicles as a safety measure and to insure navigation accuracy. To date, radars have been the primary source for range wind profile information, using weather balloons to carry a reflector kite which is tracked with a radar system. Usually several balloons are released in variable time intervals prior to the launch of every vehicle. The data collected is analyzed for wind velocity. This information is then programmed into the control and navigation system of the vehicle for appropriate navigation corrections.

The main problem to this approach is the high cost associated with maintenance and operation of high resolution radar systems. Another problem is that as the balloon travels farther away from the radar, the range and direction measured become less accurate. Also, since the velocity measurements are made based on time intervals and distances between fixes, this exaggerates the error in the wind profile data.

An alternative to radar tracking is to use a low cost GPS sensor on the balloon payload. The TIDGET™ tracking system developed by NAVSYS is less costly than radar and provides measurements of the balloon position and wind-speed in real-time. In addition, the accuracy of this system is generally better than radar. This paper compares test data taken using TIDGET and radar data from wind profiling at the Kauai Test Facility of Sandia National Laboratories.

OVERVIEW

The TIDGET Windsonde tracking system is a GPS translator based system capable of generating position and velocity information in near real-time. The system

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provides instantaneous velocity measurements rather than differencing the position between two fixes over the traveled time. Figure 1 shows a block diagram of the TIDGET Windsonde tracking system.

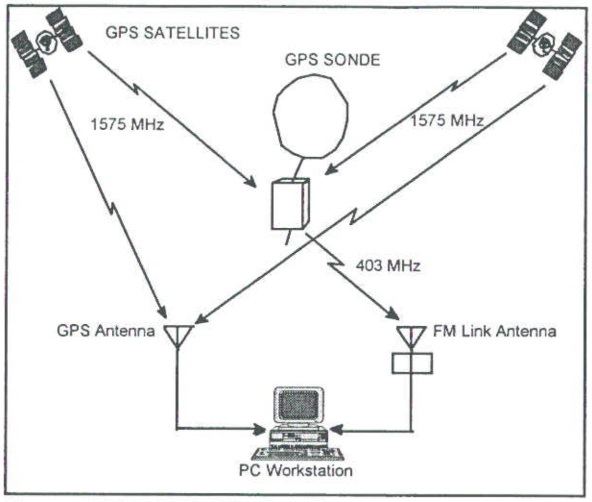


Figure 1 TIDGET Windsonde System

The TIDGET GPS sensor includes fewer components than a GPS receiver card, which results in a smaller package size, lower power consumption, and lower cost in volume. The digitized GPS data provided by the TIDGET sensor is FM modulated and transmitted to the ground processing station. The system uses the 400 MHz frequency range already allocated to the meteorological applications for data transition. The ground processing station uses internally generated differential correction for greater accuracy. The preparation of the sensor prior to release is minimal and no calibration is required. The TIDGET tracking system is a PC based system and is enclosed in a rugged and compact housing. A photo of the ground processing system is shown in Figure 2. The wind profile information is available for display on the monitor, or as an output through a serial port, or can be logged to disk.

SYSTEM ARCHITECTURE

The system consists of an airborne segment (TIDGET windsonde) and a ground station processing segment which is a PC based system.

TIDGET Windsonde: The TIDGET sensor is a digital GPS translator with a small physical size (less than 6 cu.in. including the GPS antenna). A block diagram of the TIDGET windsonde is illustrated in Figure 3. The TIDGET sensor operates at the L1 frequency and can be programmed to automatically output periodic data packets.

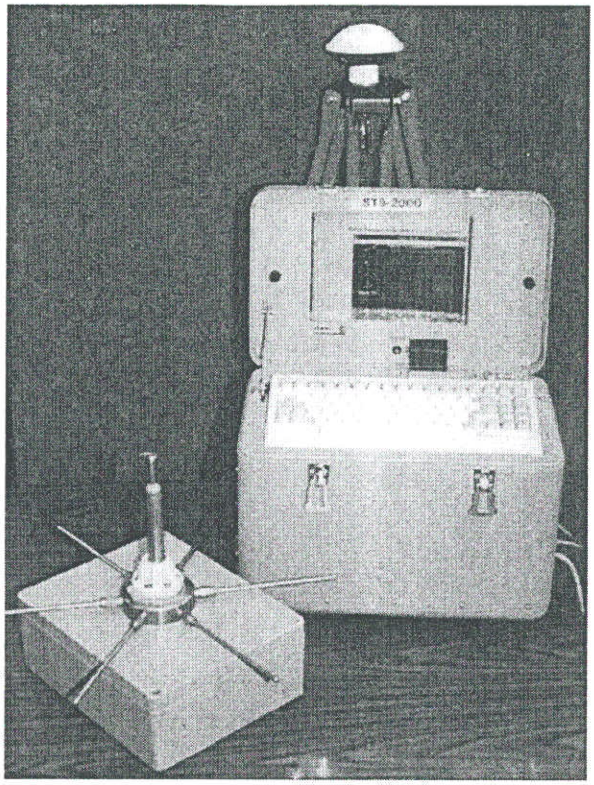


Figure 2 TIDGET Processing Station

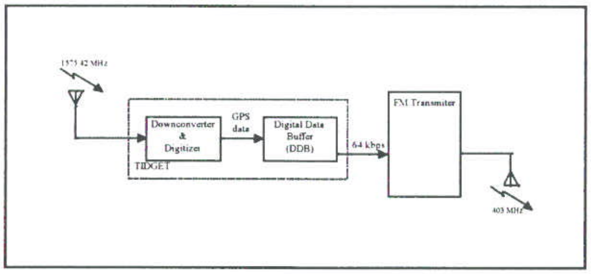


Figure 3 TIDGET Windsonde Block Diagram

The transmitted data is in the form of packets. Each packet contains a snapshot of the raw GPS data plus other information. The TIDGET also has a 16 channel multiplexing capability which allows it to include optional sensor data in each packet. Although the TIDGET default output data bit rate is set to 64 kbps, it may be programed from 200 Hz to 2 MHz using an EEPROM. The TIDGET is interfaced to a FM transmitter for data modulation and downlink over the 400 MHz meteorological bandwidth of the frequency spectrum.

TIDGET Workstation: The TIDGET workstation is a portable PC which interfaces to two antenna modules, one for the GPS reference receiver, and one for the 403 MHz FM link.

The portable PC which handles all the processing contains a synthesized FM receiver card, a data interface card, a Digital Signal Processing card, and a commercial GPS card. The processing station which is shown in Figure 2 has physical dimensions of 17"W x 10.5"D x 13"H and weighs about 30 lbs.

Both RF antenna modules are active devices and are powered by the PC power. The FM receiver handles the reception and the demodulation of the telemetry link signal. The interface card receives the demodulated data packets and hands the GPS data over to the DSP card. The DSP card processes the data for tracking the GPS satellites and provides navigation solutions. The system is capable of taking advantage of the differential correction using the information provided by the reference GPS card included in the processing station. The TIDGET workstation block diagram is shown in Figure 4.

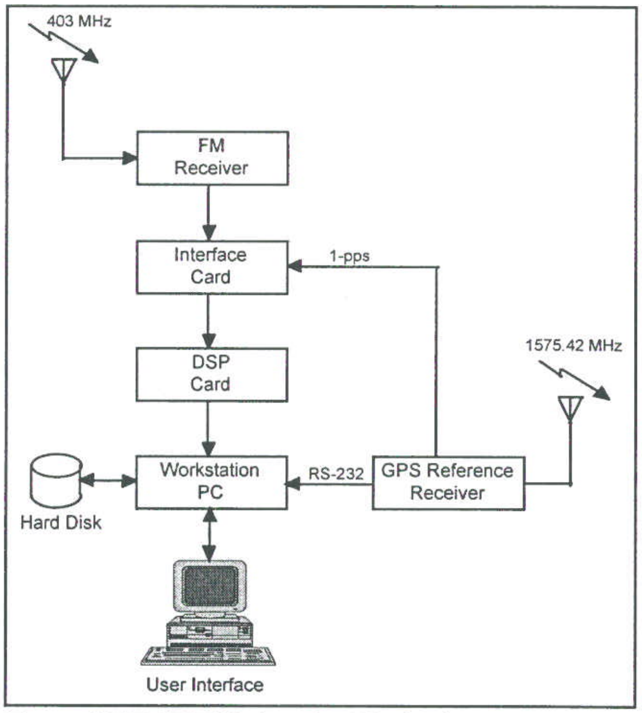


Figure 4 TIDGET Workstation Block Diagram

TEST RESULTS FROM HIGH RESOLUTION RADAR

High resolution radar data was collected at the Kauai Test Facility (KTF) for a sonde flight on June 16, 1995. This flight flew to an altitude of over 38,000 meters (>124,000 ft). The radar data was filtered with a .01 Hz filter and then reduced from 10 observations per second to 1 observation per 10 seconds. This processing eliminates the effects of the sonde motion under the balloon, but maintains the wind profiling information. To compare the NAVSYS 0.5 Hz velocity data with that from the radar, the same .01 Hz filter was used to eliminate the sonde motion from the data. The data was then time aligned and the velocity vectors were compared as a function of time. There was a data outage of the radar from about 45,000 ft to 70,000 ft.

Figures 5 and 6 show the North and East velocity profiles as a function of altitude. The data outage is clearly seen by the straight line through those altitudes. The NAVSYS velocity data is biased by 30 ft/s for plotting purposes. It is clearly seen that the NAVSYS data closely follows all of the trends that are evident in the radar data. The mean difference between the radar and TIDGET data is .185 ft/s in the North direction and .121 ft/s in the East direction with standard deviations of 2.322 and 2.054 ft/s respectively. The standard deviation of the data difference is mainly driven by the asynchronous nature of the radar data and the smoothing applied by the 0.01 Hz filter.

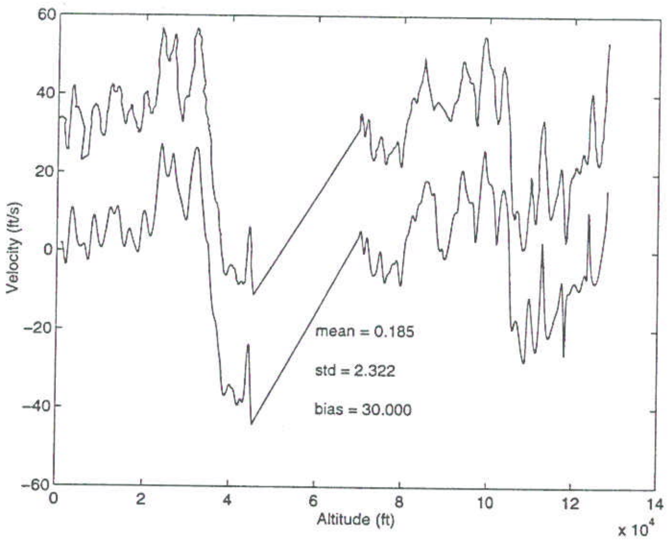


Figure 5 KTF Flight Test Data High Res. Radar, 6/16/96, North Velocity vs. Altitude

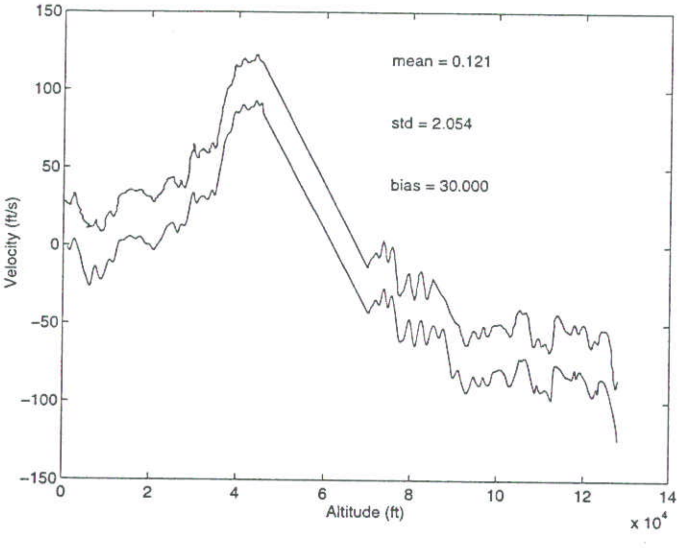


Figure 6 KTF Test Data High Res. Radar, 6/16/96, East Velocity vs. Altitude

Figure 7 shows the comparison of course as a function of altitude from the radar and from the TIDGET system. The mean difference is -.342° with a standard deviation of 5.123°. In the figure, the course from the NAVSYS data is biased by 30° for plotting purposes so the trends could be compared. Here again, the TIDGET course data closely follows the radar data. However, the effects of the smoothing and sampling on the radar data are evident. This effect is particularly evident around the 1000 ft altitude level.

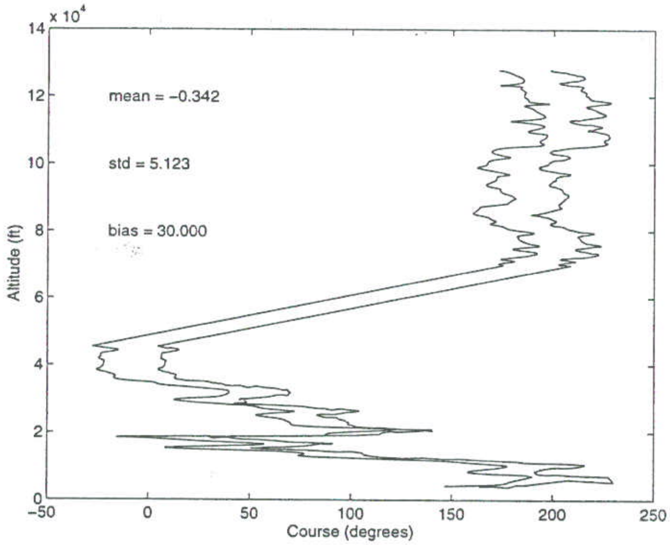


Figure 7 KTF Test Data High Res. Radar, 6/16/96, Course vs. Altitude

CONCLUSIONS

The NAVSYS TIDGET sonde tracking system compares very well to the precision radar in providing real-time velocity profiling. The effects of the different sampling rates between the radar and the TIDGET system and the filtering of the data play a role in the statistical evaluation of the data. Overall, the TIDGET system compares with the radar to below the .2 ft/s level with a standard deviation of about 2 ft/s. Much of the variance noise is caused by the 0.01 Hz filtering of the radar data. The increased performance and higher data rate (0.5 Hz) provided by the TIDGET tracking system will provide higher resolution wind data at a reduced cost than operating a precision radar.

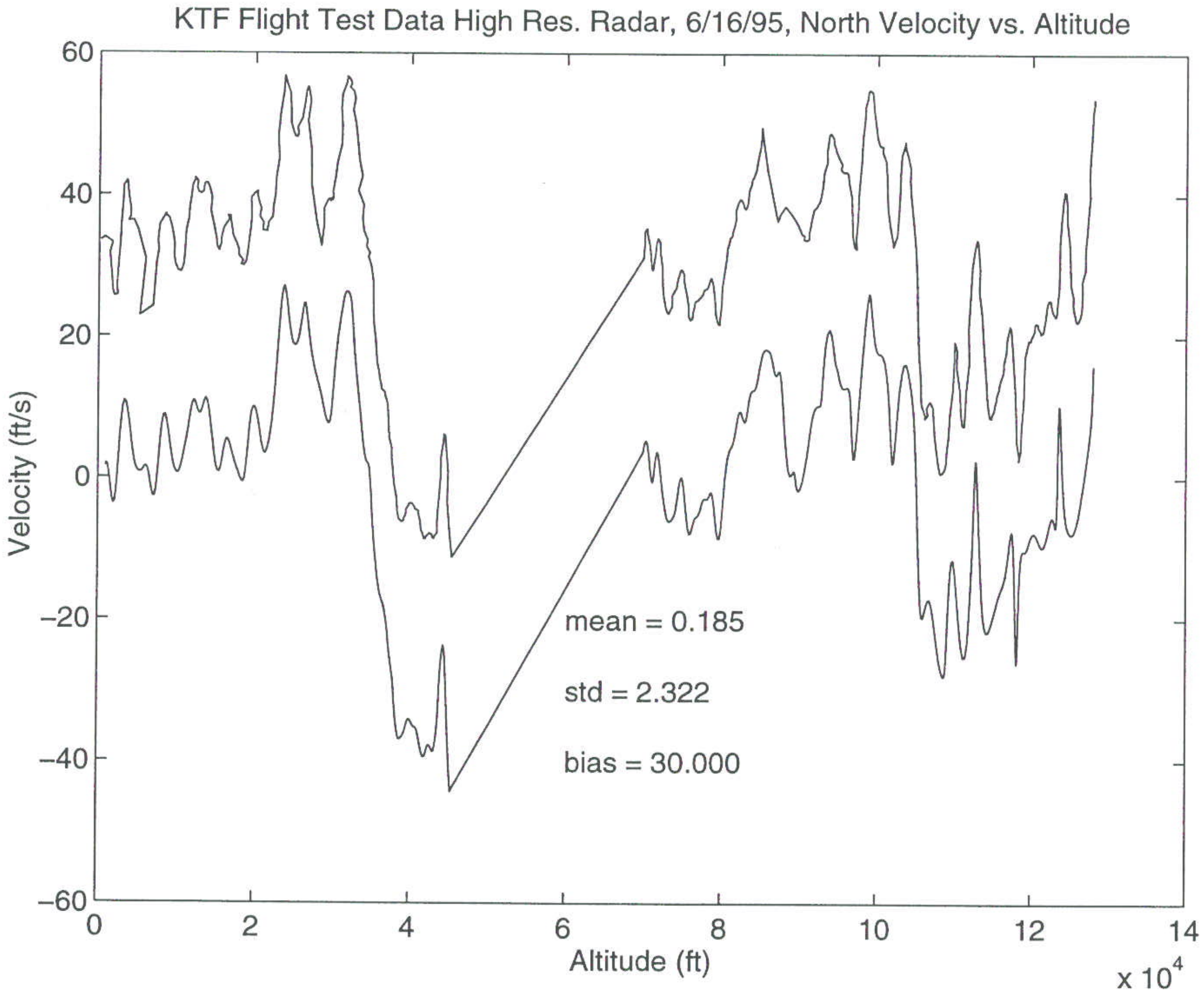

KTF Flight Test Data High Res. Radar, 6/16/95, North Velocity vs. Altitude
Velocity (ft/s)
60
40
20
0
−20
−40
−60
Altitude (ft)
0
2
4
6
8
10
12
14
x 10^4
mean = 0.185
std = 2.322
bias = 30.000

FIG. 1

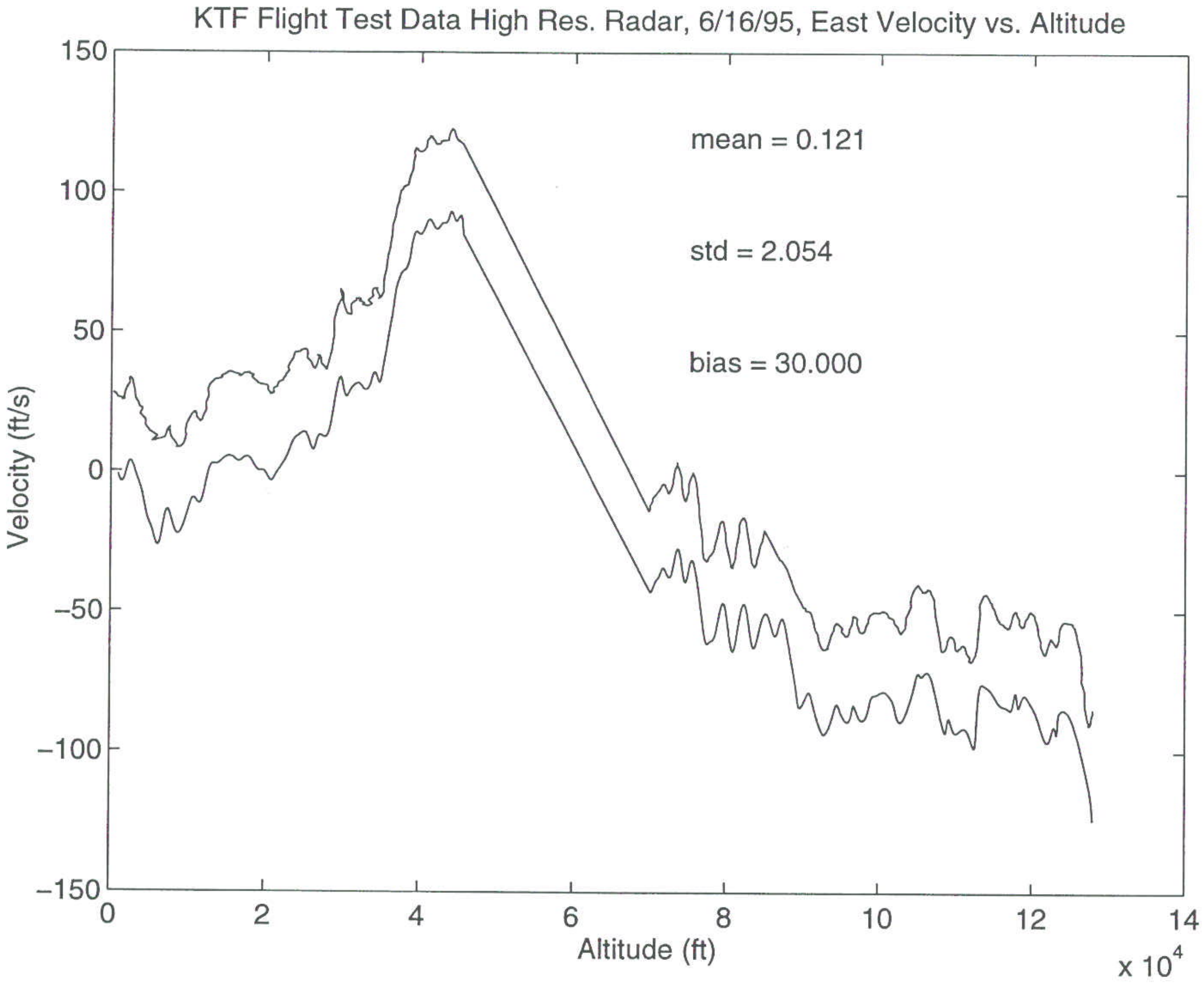

KTF Flight Test Data High Res. Radar, 6/16/95, East Velocity vs. Altitude
mean = 0.121
std = 2.054
bias = 30.000
Velocity (ft/s)
150
100
50
0
−50
−100
−150
0
2
4
6
8
10
12
14
Altitude (ft)
x 10^4

FIG. 2

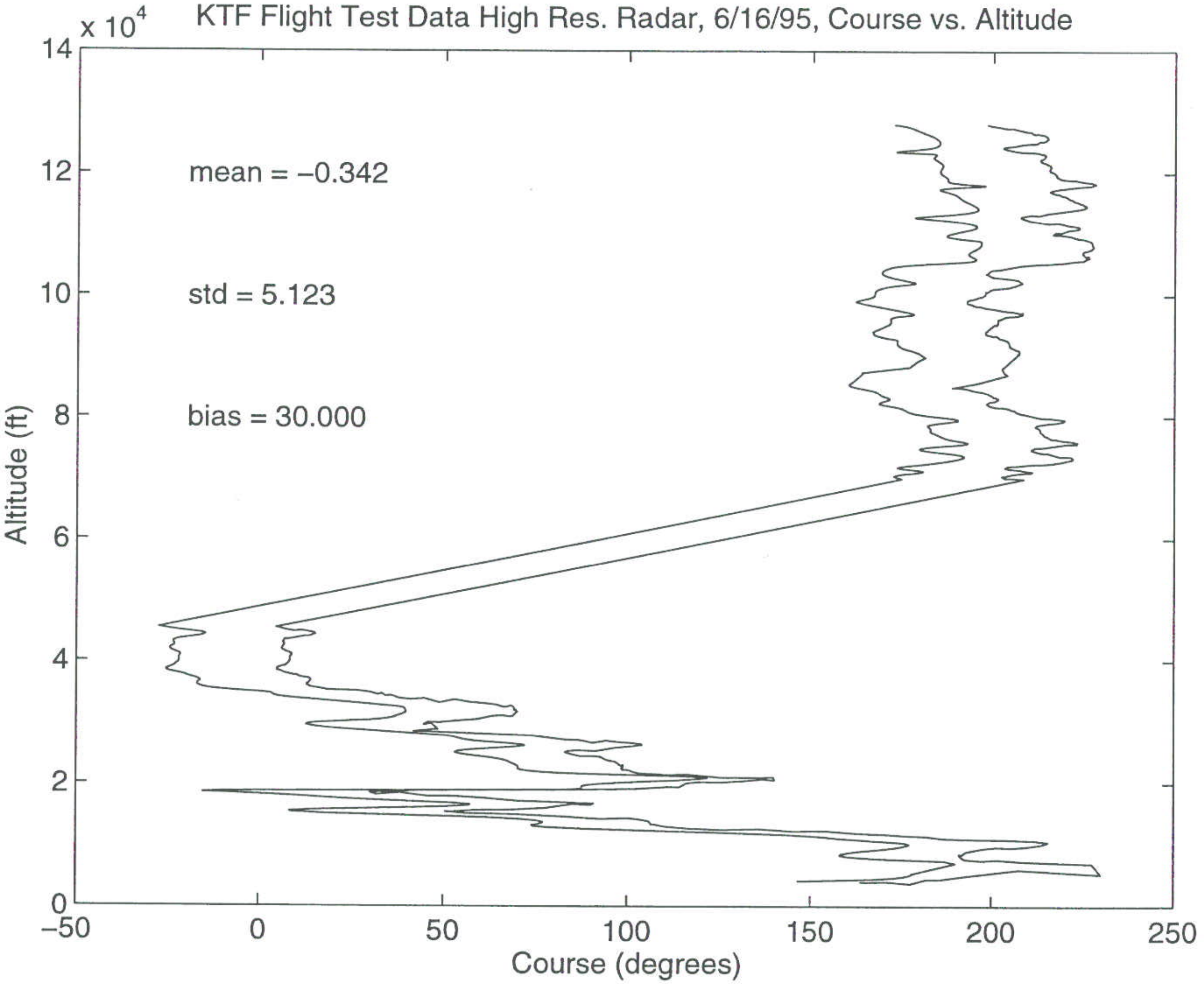
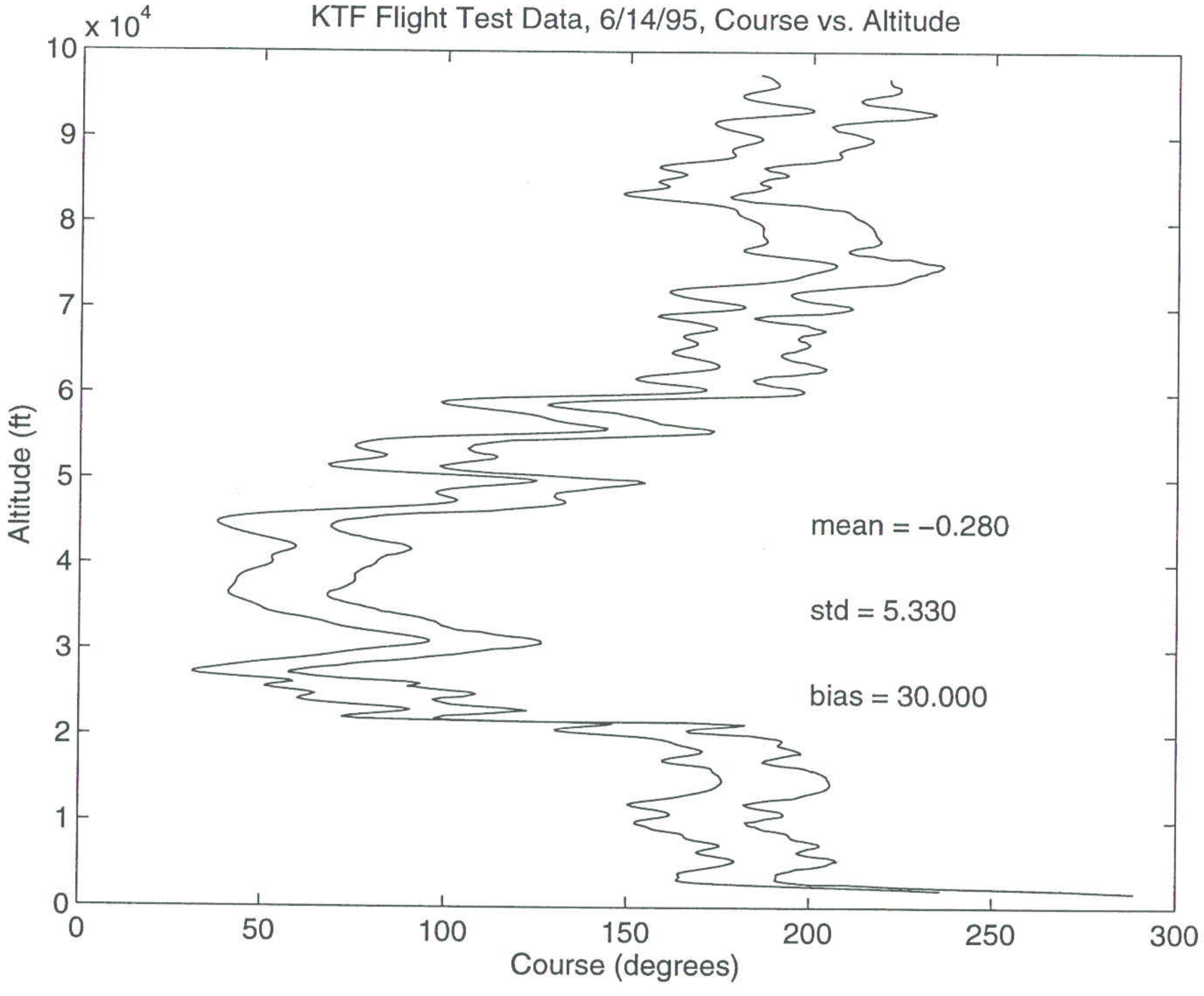
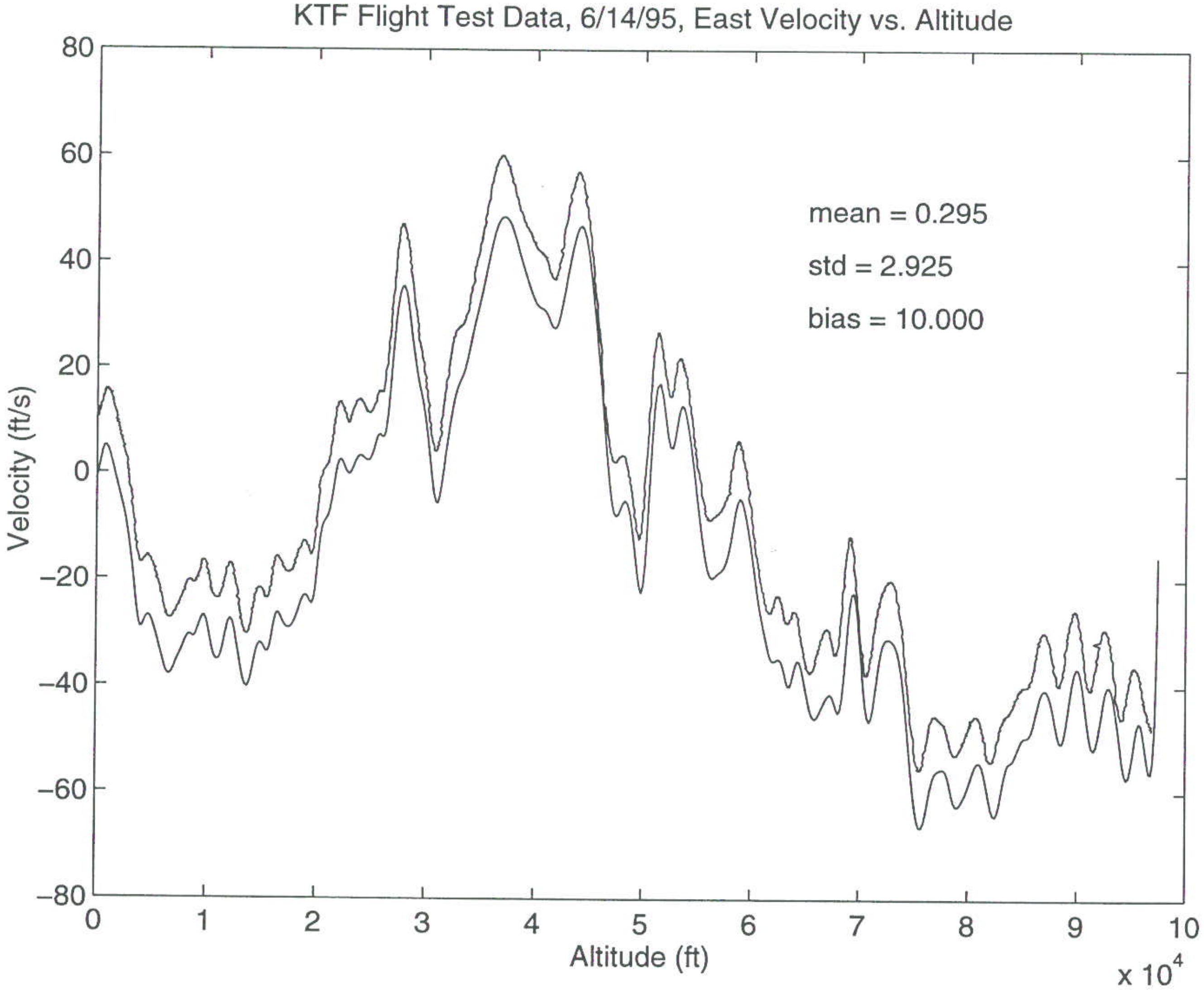
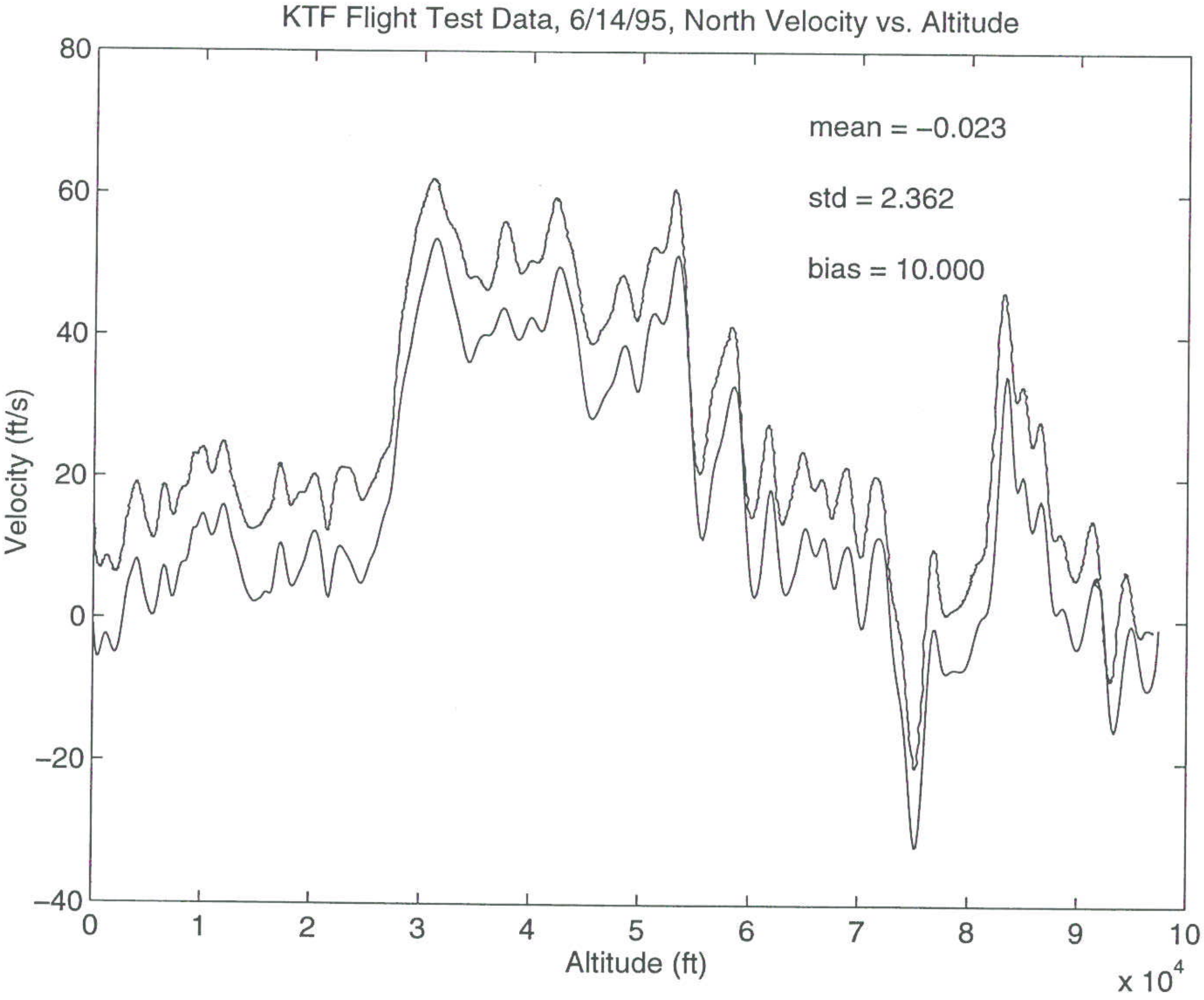

KTF Flight Test Data High Res. Radar, 6/16/95, Course vs. Altitude
x 10^4
14
12
10
8
6
4
2
0
Altitude (ft)
mean = −0.342
std = 5.123
bias = 30.000
−50
0
50
100
150
200
250
Course (degrees)

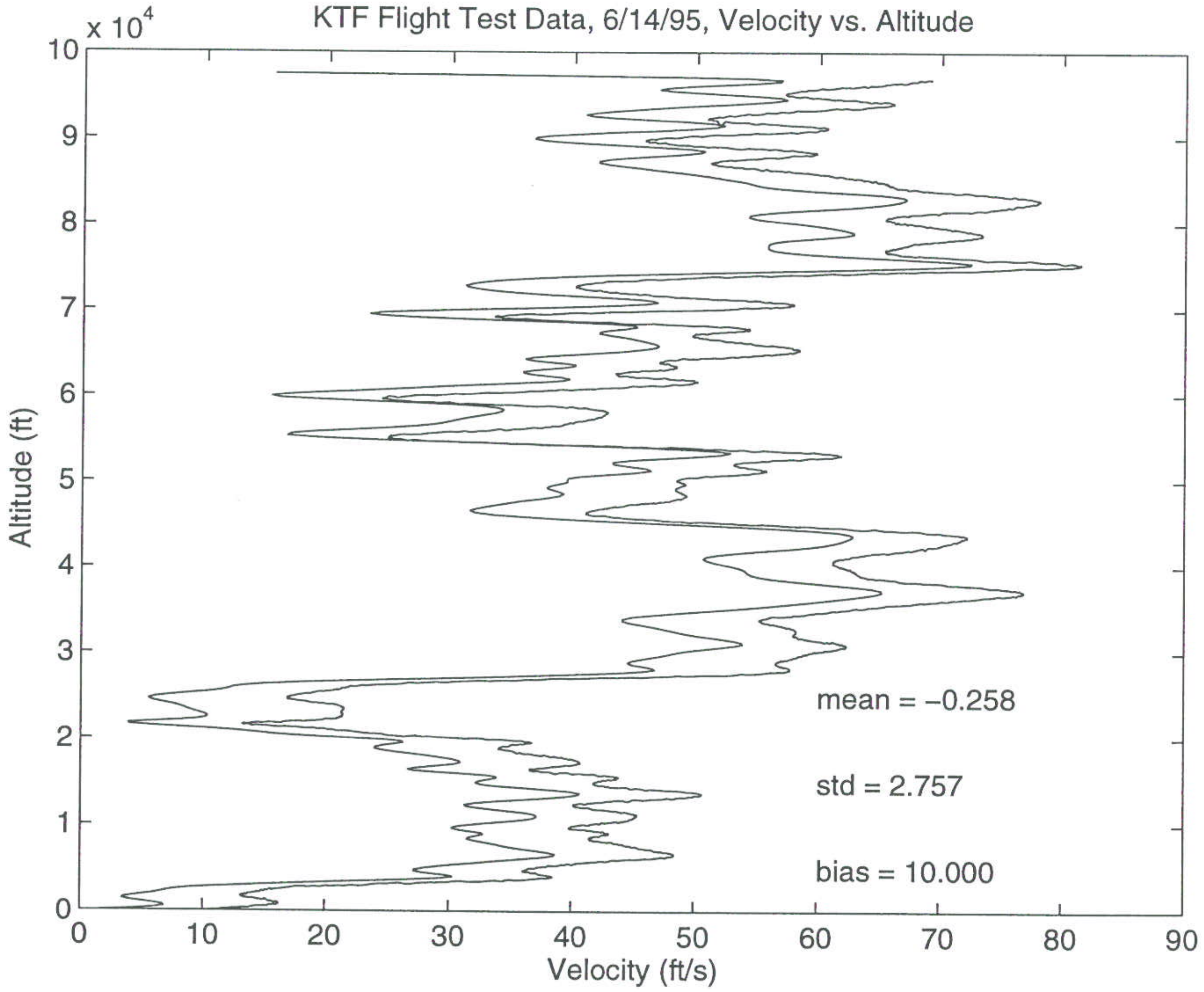
FIG. 3

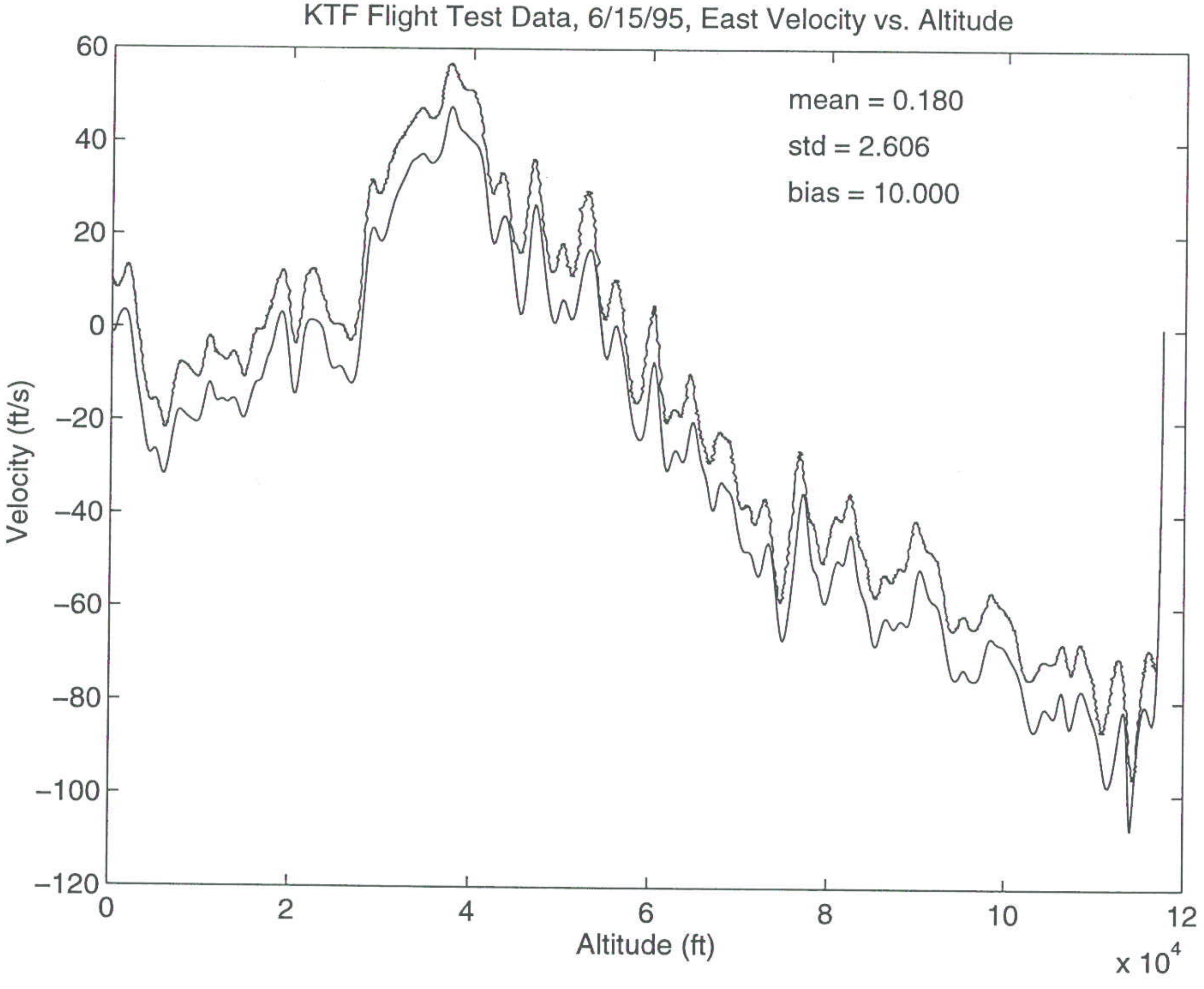

KTF Flight Test Data, 6/14/95, Course vs. Altitude
x 10^4
10
9
8
7
6
5
4
3
2
1
0
Altitude (ft)
0
50
100
150
200
250
300
Course (degrees)
mean = −0.280
std = 5.330
bias = 30.000

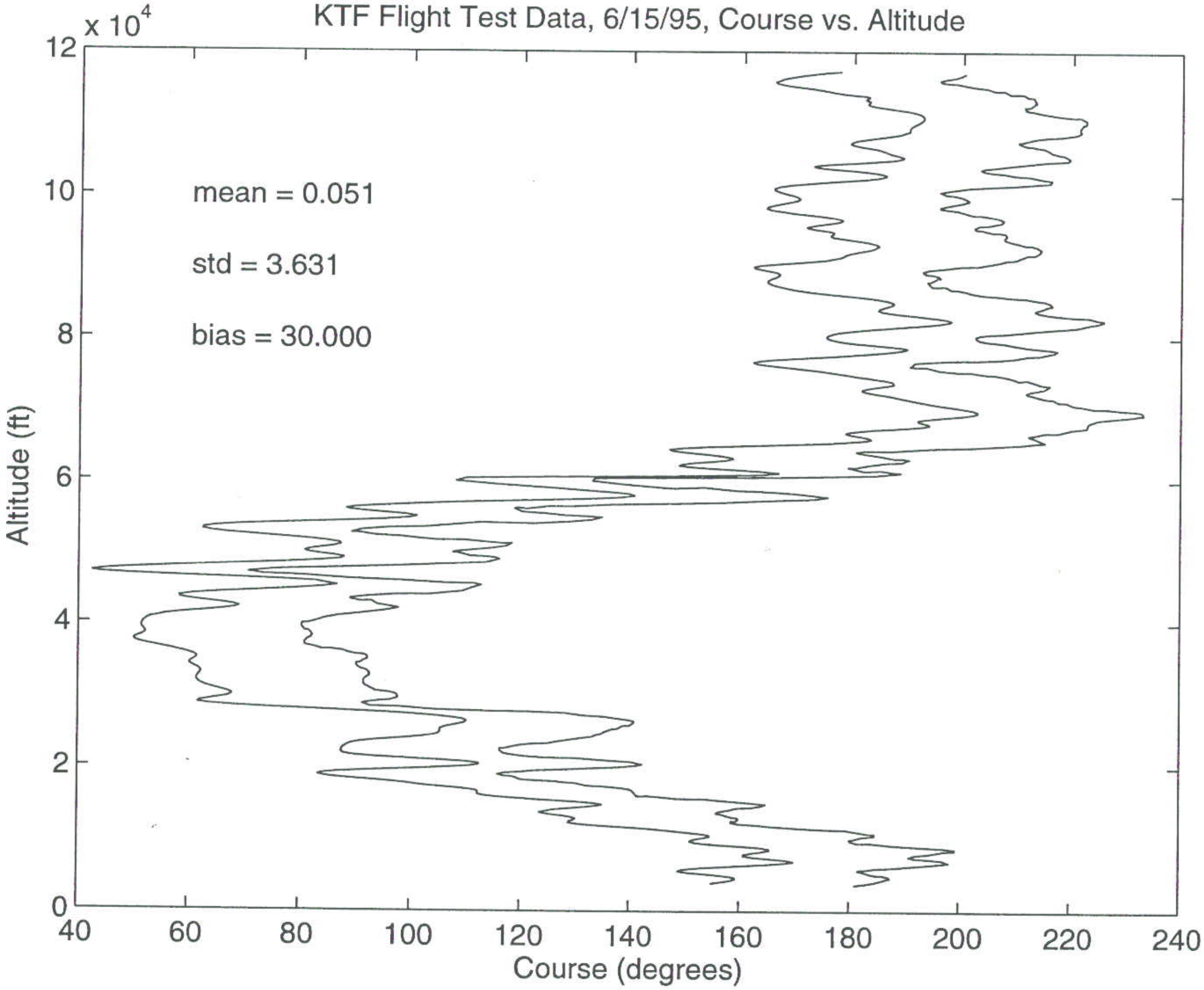

KTF Flight Test Data, 6/14/95, East Velocity vs. Altitude
80
60
40
20
0
−20
−40
−60
−80
Velocity (ft/s)
0
1
2
3
4
5
6
7
8
9
10
Altitude (ft)
x 10^4
mean = 0.295
std = 2.925
bias = 10.000



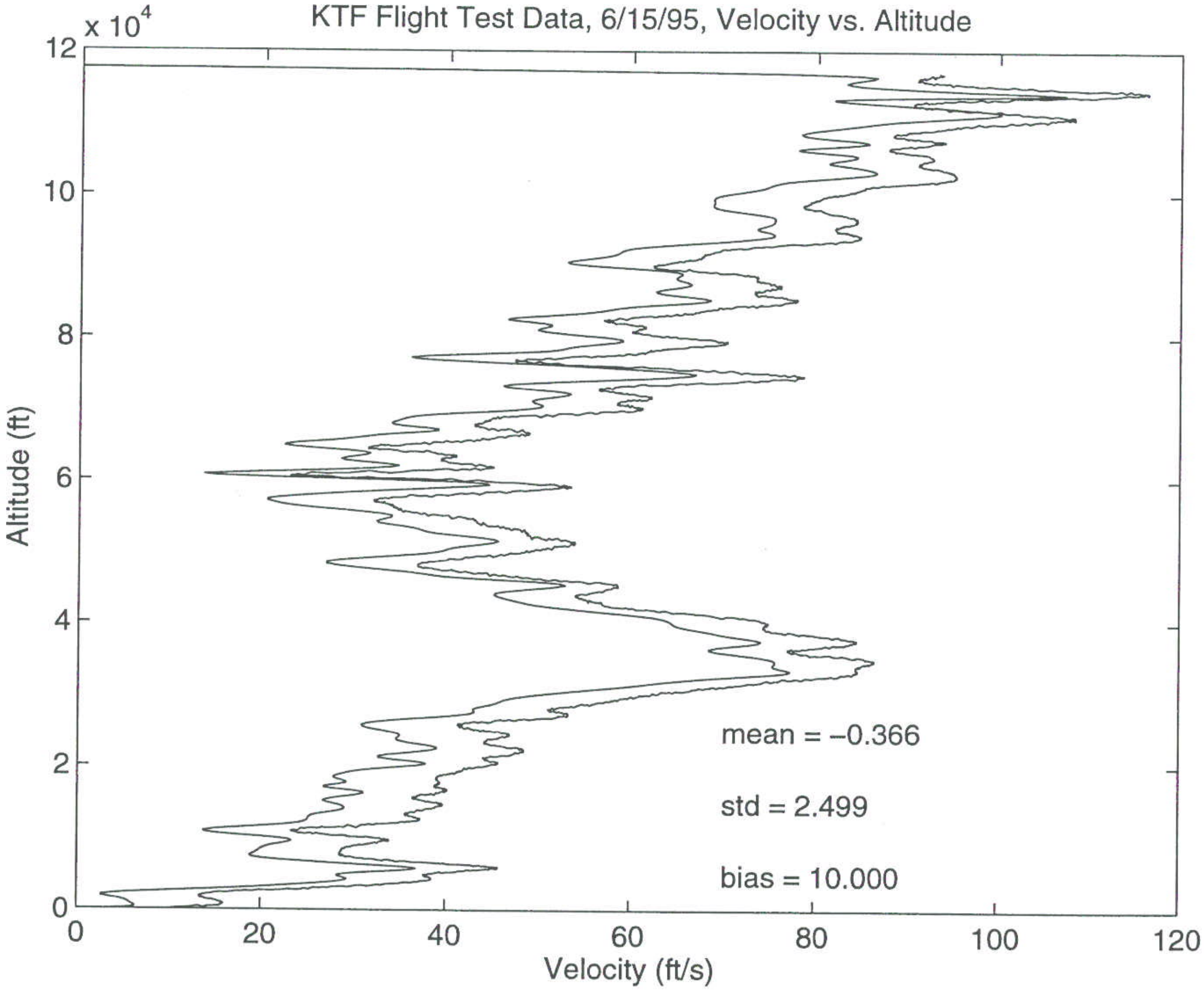
KTF Flight Test Data, 6/14/95, North Velocity vs. Altitude

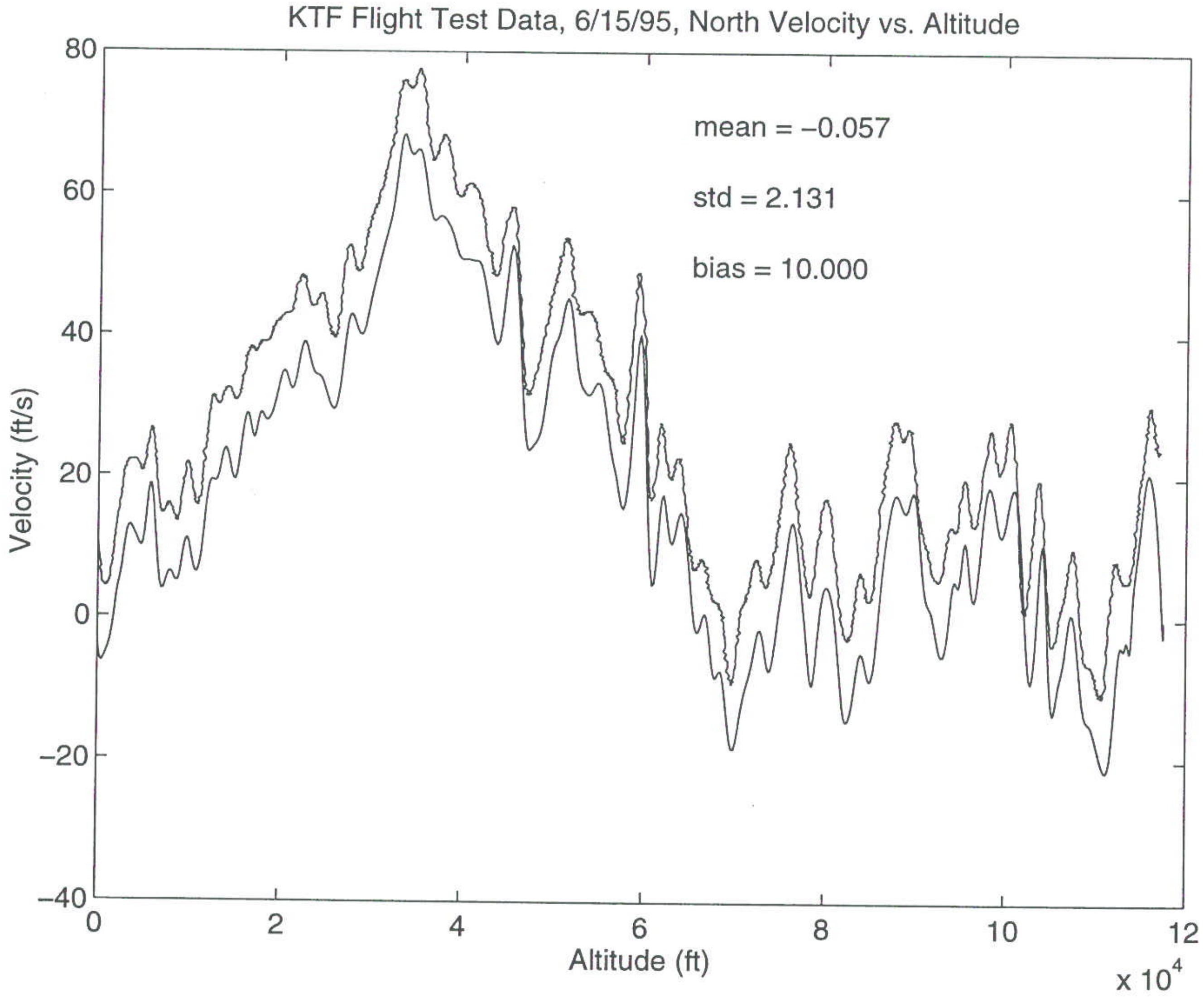

KTF Flight Test Data, 6/14/95, Velocity vs. Altitude
x 10^4
10
9
8
7
6
5
4
3
2
1
0
Altitude (ft)
0
10
20
30
40
50
60
70
80
90
Velocity (ft/s)
mean = −0.258
std = 2.757
bias = 10.000

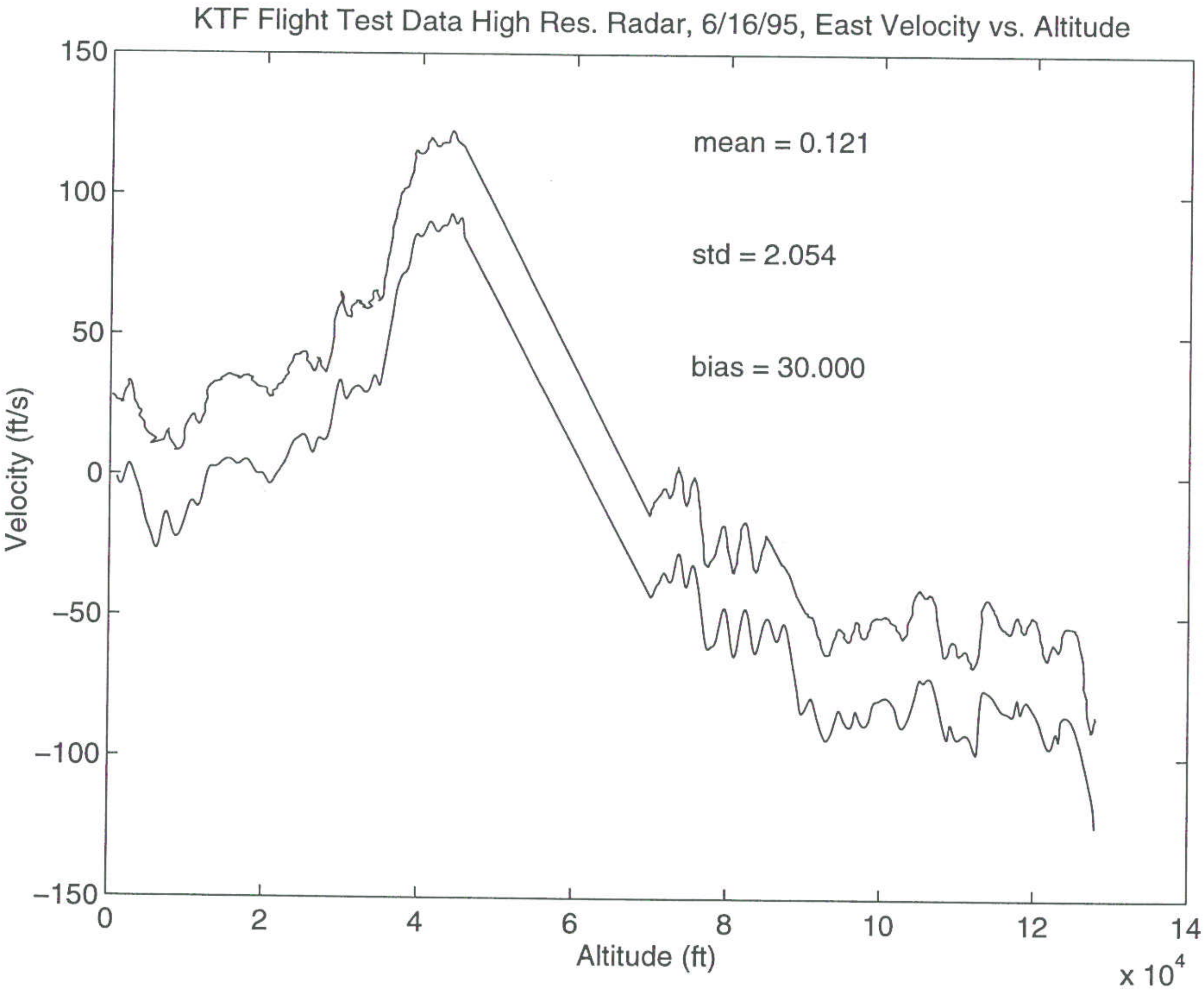

KTF Flight Test Data, 6/15/95, East Velocity vs. Altitude
mean = 0.180
std = 2.606
bias = 10.000
Velocity (ft/s)
60
40
20
0
−20
−40
−60
−80
−100
−120
Altitude (ft)
0
2
4
6
8
10
12
x 10^4

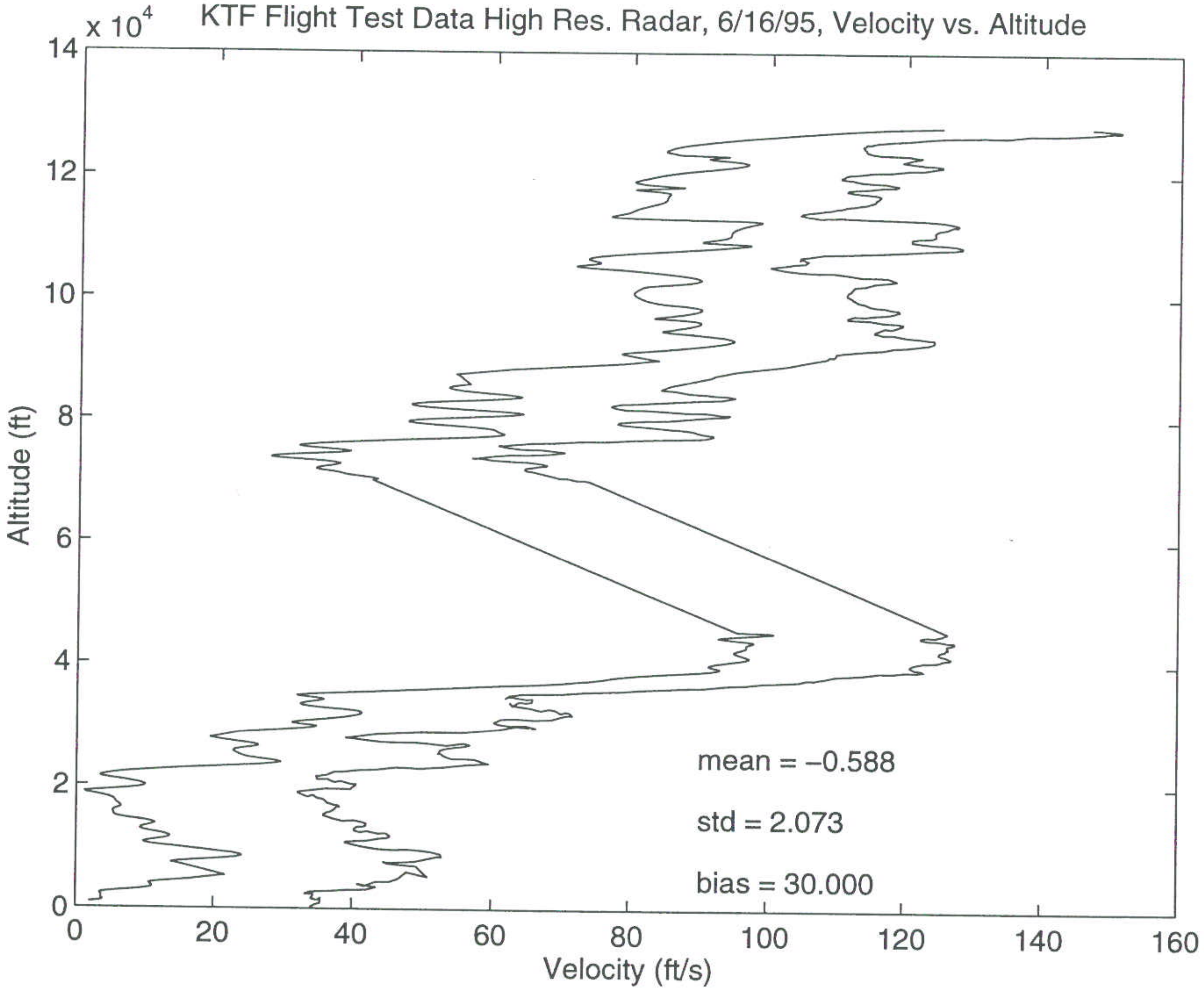


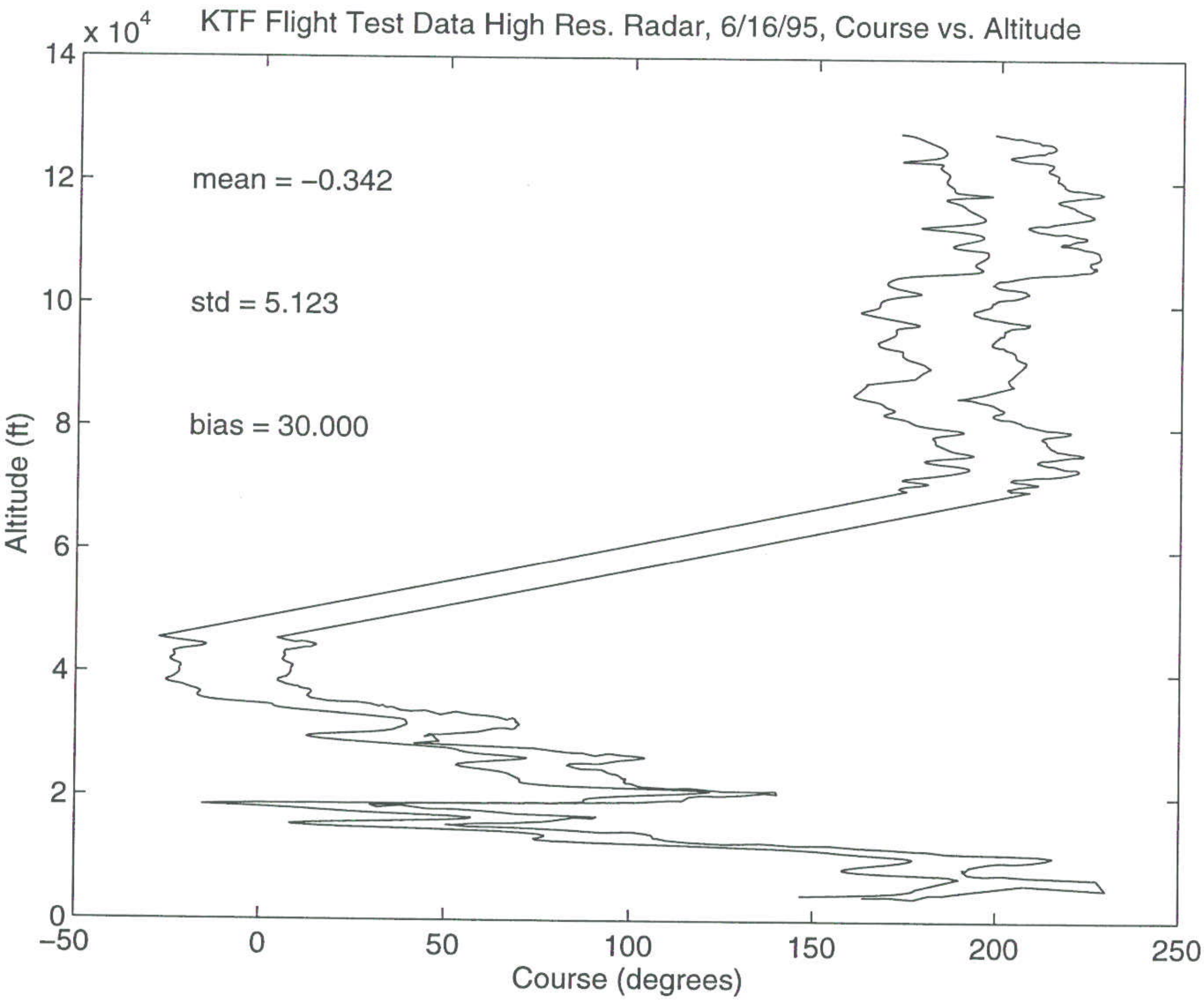
KTF Flight Test Data, 6/15/95, Course vs. Altitude

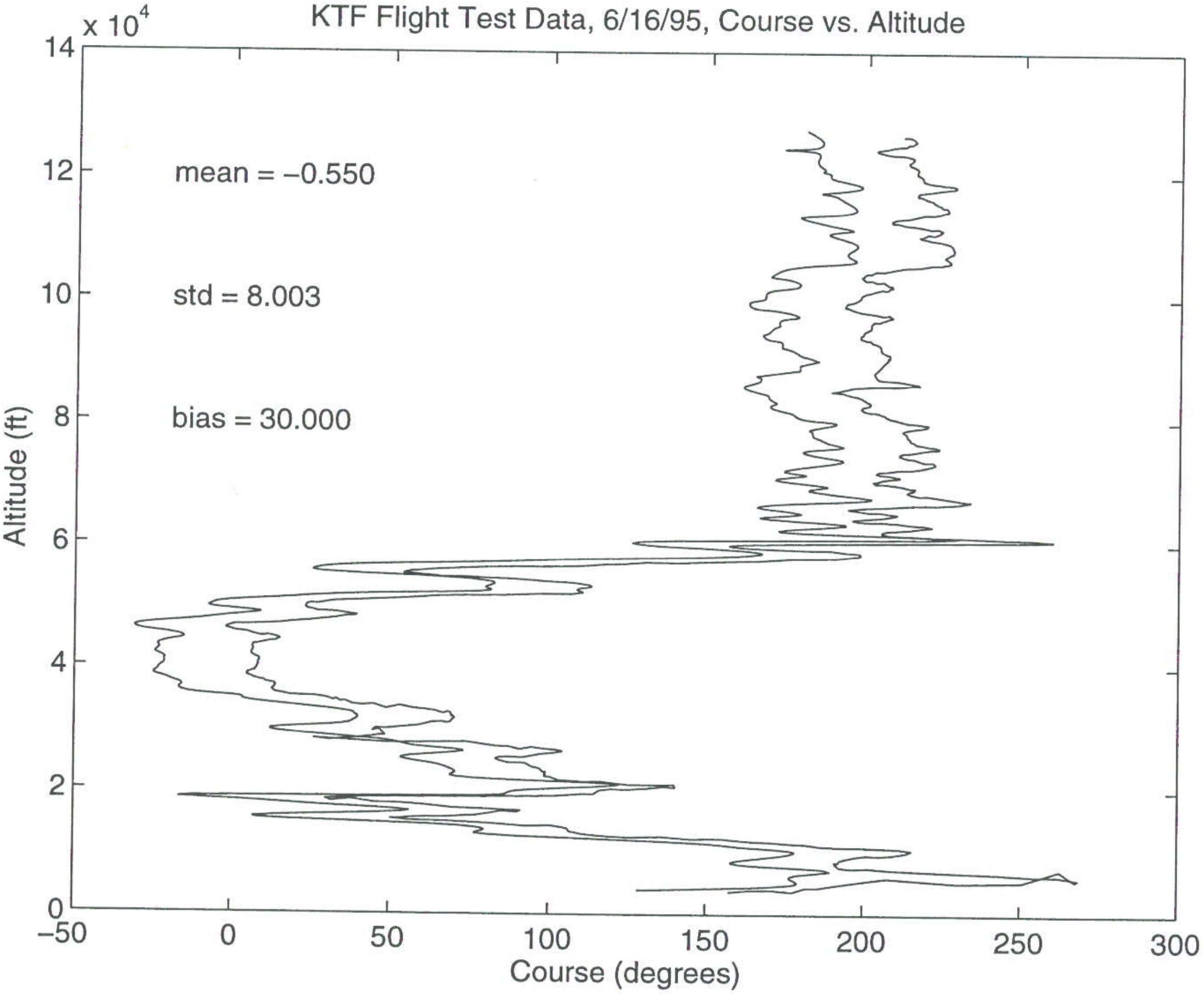

KTF Flight Test Data, 6/15/95, Velocity vs. Altitude
x 10^4
12
10
8
6
4
2
0
Altitude (ft)
0
20
40
60
80
100
120
Velocity (ft/s)
mean = −0.366
std = 2.499
bias = 10.000


KTF Flight Test Data, 6/15/95, North Velocity vs. Altitude
mean = −0.057
std = 2.131
bias = 10.000
Velocity (ft/s)
80
60
40
20
0
−20
−40
Altitude (ft)
0
2
4
6
8
10
12
x 10^4


KTF Flight Test Data High Res. Radar, 6/16/95, East Velocity vs. Altitude
150
100
50
0
−50
−100
−150
Velocity (ft/s)
0
2
4
6
8
10
12
14
Altitude (ft)
x 10^4
mean = 0.121
std = 2.054
bias = 30.000


KTF Flight Test Data High Res. Radar, 6/16/95, Velocity vs. Altitude
x 10^4
14
12
10
8
6
4
2
0
Altitude (ft)
0
20
40
60
80
100
120
140
160
Velocity (ft/s)
mean = −0.588
std = 2.073
bias = 30.000


KTF Flight Test Data High Res. Radar, 6/16/95, Course vs. Altitude
x 10^4
14
12
10
8
6
4
2
0
Altitude (ft)
mean = −0.342
std = 5.123
bias = 30.000
−50
0
50
100
150
200
250
Course (degrees)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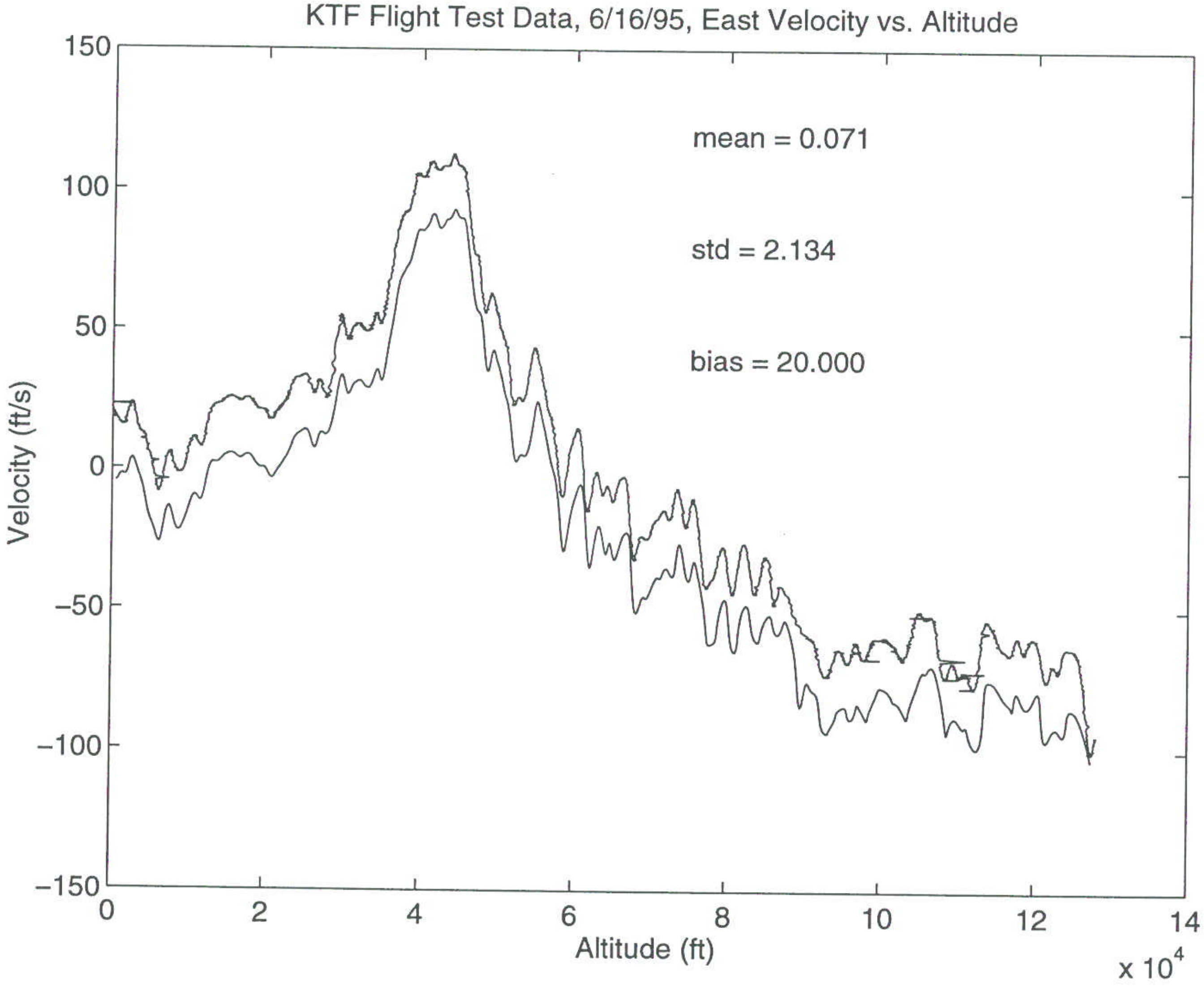
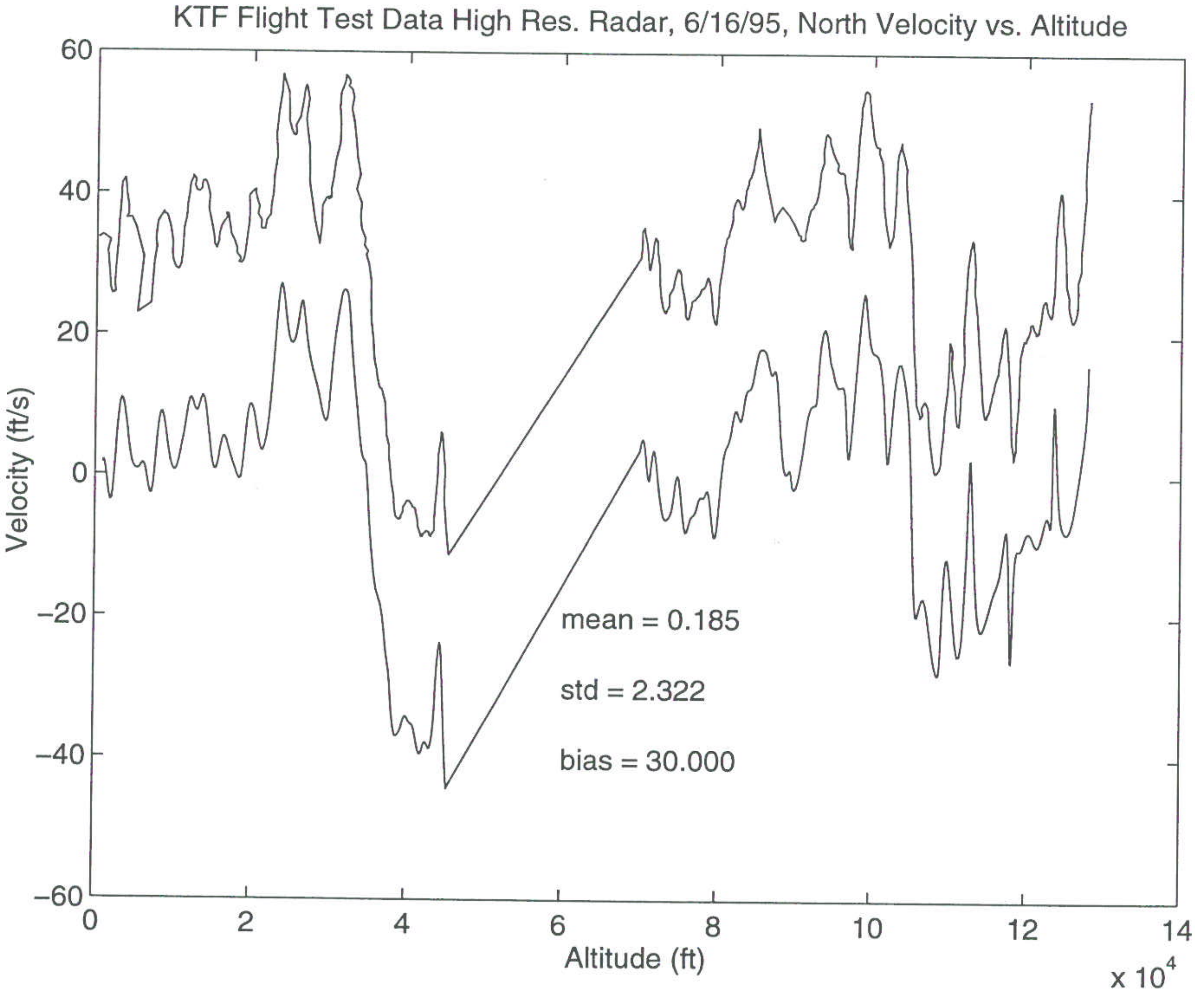
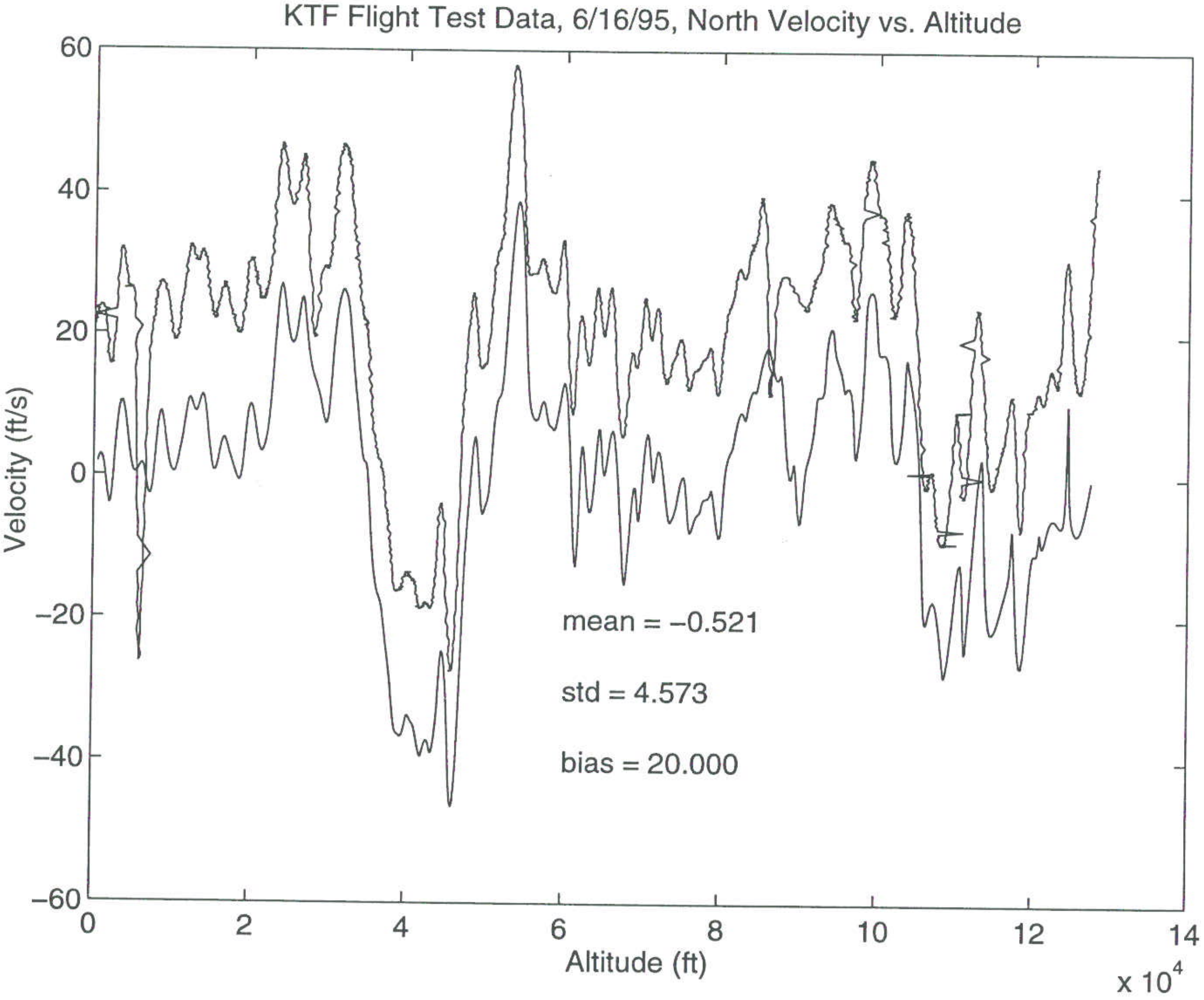
x 10^4
14
12
10
8
6
4
2
0
Altitude (ft)
mean = −0.550
std = 8.003
bias = 30.000
−50
0
50
100
150
200
250
300
Course (degrees)


KTF Flight Test Data, 6/16/95, East Velocity vs. Altitude
mean = 0.071
std = 2.134
bias = 20.000
Velocity (ft/s)
150
100
50
0
−50
−100
−150
Altitude (ft)
0
2
4
6
8
10
12
14
x 10^4



KTF Flight Test Data High Res. Radar, 6/16/95, North Velocity vs. Altitude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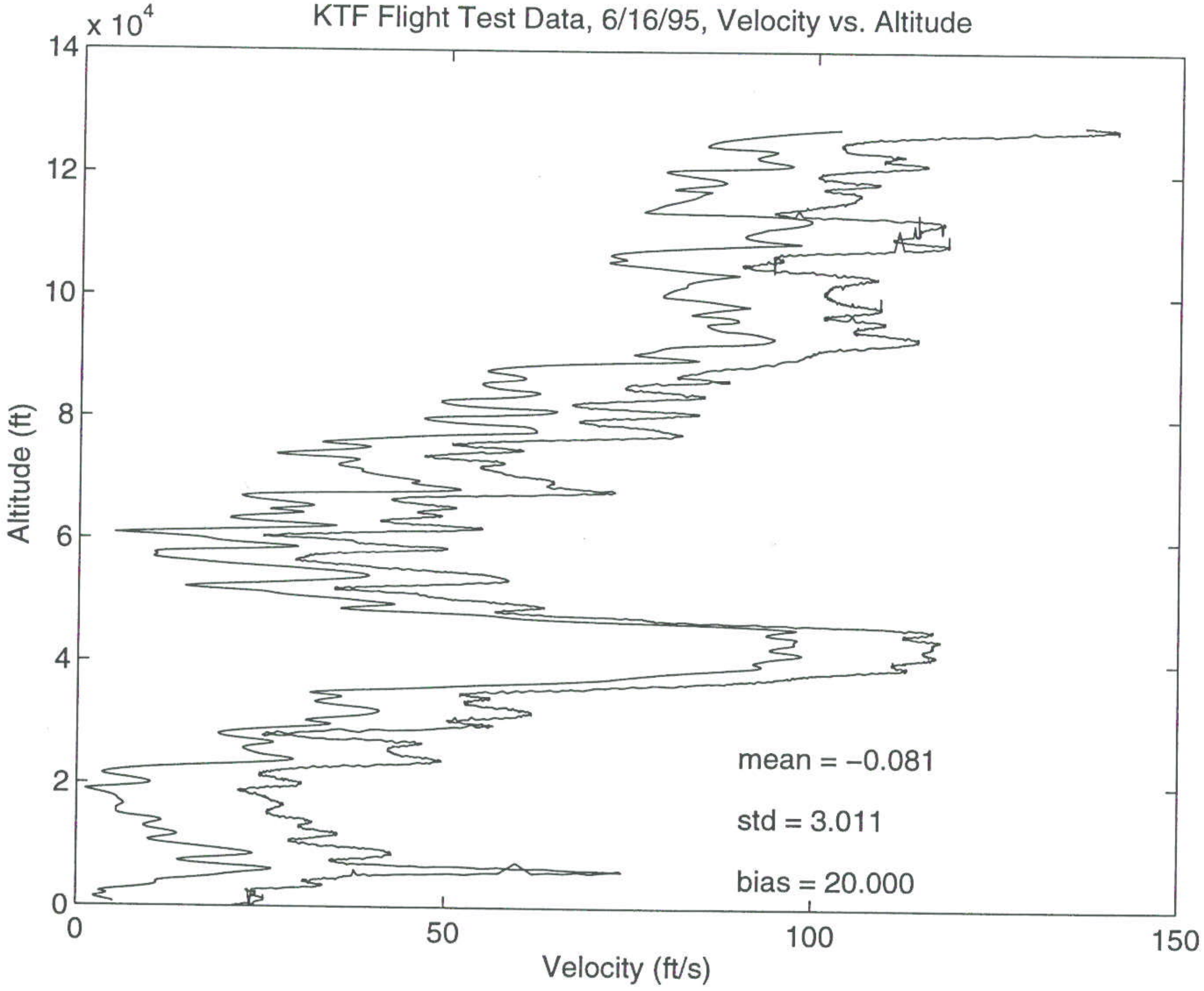
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