A STUDY OF ERRORS IN PREDICTING ARRIVAL FIX TIMES IN AIR TRAFFIC CONTROL

BY

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Submitted to the Department of Aeronautics and Astronautics
in Partial Fulfillment of the Requirements for the
Degree of

Master of Science in Aeronautics and Astronautics
at the

Massachusetts Institute of Technology

June 1993

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ABSTRACT

As the US air line industry experienced remarkable growth during the economic expansion of the 1980's and air traffic increased drastically, terminal airspace around busy airport became more and more crowded. The accompanying effects were the occurrence of congestion and delay. To alleviate the effects of this delay, it has become necessary to introduce Traffic Flow Management processes which depend critically on the accurate prediction of arrival rates of traffic at busy airports. The objective of this thesis is to provide statistical evidence about the accuracy of Estimated Fix Time Arrivals (EFTAs) at terminal area entry fixes for airborne aircraft as a function of " Time-to-go " (T) . This is needed to assess the accuracies of the expected arrival rates at a congested airport. The accuracies of the EFTAs are expressed as a mean error, a standard deviation σ, and there is a variation of σ with "Time-to-go" (T). Furthermore, we also investigate the effects of initial climb on $\sigma(T)$. The results of these studies are quite important for properly executing Traffic Flow Management , and affect the possibility of developing new concepts.

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Acknowledgments

My sincerest thanks to Professor Robert W. Simpson who has supervised and supported the research leading to this thesis. I have benefited a great deal from his kind help and expert advice in the course of this research. It is a tremendous privilege for me to have this opportunity to work with Professor Simpson.

I would also like to thank my good friends here in MIT: Kuang-Han Chen, Nai-Hsin Ting for their valuable suggestions upon the thesis. I am grateful to Elizabeth Zotos, Catherine E. Carter, and Clare Williman for their kind helps.

Lastly, I would like to thank my parents, Shui-Li Chiang and Mei-Ying Yang Chiang, for their unconditional love and financial support.

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Chapter 1

Introduction

1.1 Motivation of the Thesis

As the US air line industry experienced remarkable growth during the economic expansion of the 1980's and air traffic increased drastically, terminal airspace around busy airport became more and more crowded. The accompanying effects were the occurrence of congestion and delay. To alleviate the effects of this delay, it has become necessary to introduce Traffic Flow Management processes which depend critically on the accurate prediction of arrival rates of traffic at busy airports. The objective of this thesis is to provide statistical evidence about the accuracy of Estimated Fix Time Arrivals (EFTAs) at terminal area entry fixes for airborne aircraft as a function of " Time-to-go " (T) . This is needed to assess the accuracies of the expected arrival rates at a congested airport. The accuracies of the EFTAs are expressed as a mean error, a standard deviation σ, and there is a variation of σ with "Time-to-go" (T). Furthermore, we also investigate the effects of initial climb on $\sigma(T)$. The results of these studies are quite important for properly executing Traffic Flow Management , and affect the possibility of developing new concepts.

1.2 Structure of the Thesis

The remainder of this thesis is devided into five chapters. Chapter 2 contains a brief description of the current Estimated Traffic Management System (ETMS), and some background information referring to its National Airspace System (NAS) messages, Time Type (TPP), and Flight Time Modeling. Those are needed for us to understand the following chapters' statistical analysis.

Chapter 3 addresses the methodology used in the statistical analysis. It explains how to pick up the sample points from air flights in four cities (Denver, Orlando, Minneapolis-St. Paul, and Phoenix), and also shows some example plots of EFTA errors versus Time-to-go, the distribution of EFTA errors for different discrete time-to-go values (T=30,60,90,120 mins, etc.), and the trend of $\sigma(T)$ with time -to-go.

Chapter 4 gives the aggregate analysis of the results we obtained in chapter 3 for four cities and all cities, and compares the different cities with one another.

Chapter 5 provides the conclusion about the thesis and an overview of further research in this topic.

Chapter 2

Introduction

2.1 Enhanced Traffic Management System (ETMS)

The Enhanced Traffic Management System(ETMS) assists the FAA in the performance of air traffic management. Air traffic management is the strategic control of traffic flow; its purpose is to reduce airborne delays and congestion, and to increase the overall output of the National Airspace System (NAS).

Air traffic management is performed through a hierarchical organization. At the top is the Air Traffic Control System Command Center (ATCSCC) which is concerned with the management of the nationwide traffic problems. The next stage consists of Traffic management Units (TMUs) at the contiguous U.S. Air Route Traffic Control Centers (ARTCCs). The final stage of the hierarchy is the TMUs at the Terminal Radar Approach Control (TRACON) facilities.

The ETMS is associated with the Advanced Traffic Management System (ATM) of which goal is to develop and evaluate new concepts for traffic management automation. The ETMS implementation currently represents the first two of the five ETMS

development phases. The first phase was the development of the Aircraft Situation Display (ASD), which can graphically display current aircraft positions. The second phase is the development of the monitor and alert function. Monitor/Alert can provide a forecast of traffic demands for all airports, sectors, and fixes of interest in U.S. and alerts for the situation where these forecasts exceed any desired set of alert thresholds.

2.2 Background Information

To conduct Traffic Flow Management, the ATC computer in each of the ARTCCs of the NAS sends recurrent messages on the position of all its aircraft (and other information) to the ATM system at 5 minutes intervals. This allows the display of the nation's air traffic on a single display called the ASD(Aircraft Situation Display). From these messages, it is possible to determine the current groundspeed of each aircraft, and using its flight planned route to estimate arrival times at future waypoints. Each flight plan is analyzed to identify a set of "events" which are important during the flight (e.g. sector or Center boundary crossing, enroute waypoints, crossing into TRACONs at " Arrival" or "Entry" fixes, etc.).

2.2.1 NAS Messages

There are seven NAS messages received by ETMS. We provide a brief description about each message:

•Flight schedule (FS): it provides information on scheduled flights before a flight plan is filed.

•Flight plan (FZ): its purpose is to transmit the intentions of a flight as filed with the NAS. It provides the routing, altitude, and airspeed.

•Amendment (AF): its purpose is to amend a flight's intentions that were previously filed with the NAS.

•Cancellation (RZ): its purpose is to cancel the a flight plan previously filed with the NAS.

•Departure(DZ): signifies the activation of a proposed flight, whenever the radar surveillance establishes that the flight is airborne and establishes a track file for that aircraft.

•ARTCC Boundary Crossing (UZ): transmits the time at which an aircraft has left the airspace of an Air Route Traffic Control Center and enters new airspace.

•Position Update(TZ): Transmits the current position, altitude, and groundspeed of a flight as tracked by the NAS[1]

•Arrival (AZ): signifies the termination of an active flight after it enters the airspace of its destination TRACON (Terminal Radar Control Center).

2.2.2 Time Type(TTP)

There are three types of information concerning time values in the above messages as follows:

TTP=4 - updated directly from TZ

[1]A position update is generated for each flight at least once every 5 minutes. A single TZ may contain position update for multiple flights.

TTP=5 - interpolated from other TZ events

TTP=6 - predicted times

Either 4 or 5 corresponds to our best estimate of the actual time at any Entry fix.

2.2.3 Flight Time Modeling

The description of the ETMS flight time modeling is divided into three sections. Section 2.2.3.1 describes how the ETMS models departure times. 2.2.3.2 describes how the ETMS predicts time for the other events in a flight's event list . Section 2.2.3.3 describes how the ETMS updates event times based on the data received in position update (TZ) messages.

2.2.3.1 Departure Time Modeling

The ETMS receives departure times from incoming flight plan data messages and initially expresses all departure event times as wheels-up times[1] . The ETMS converts gate pushback times[2] to wheel-up times by adding a taxi time estimate which is determined from historical data for each airline operating at an airport. It is expected that an actual departure message (DZ) will be received within 5 minutes of wheels-up times, and it will activate the flight plan.

The ETMS also tracks observed departure delays. When it observes that a flight has not been activated five minutes after its expected departure time, it adds five minutes

[1] Wheels-up times refer to the time that the flight actually takes off.

[2] Gate pushback times refer to the time that a flight expects to push back from the gate at a terminal after loading passengers.

to the modeled departure time. (i.e. it is waiting to see when the flight will be activated without any knowledge of why it is being delayed)

2.2.3.2 En Route Time Modeling

The computations for estimated event times while an aircraft is airborne are based on the latest groundspeed and the distance to the future event. Before takeoff, ETMS uses flight plan data using the forecasted wind vector for the nearest location and combines aircraft airspeed vector with wind vector to predict the speed over ground at each enroute event. The ETMS then uses the groundspeed with the distances between events to compute the next event times.

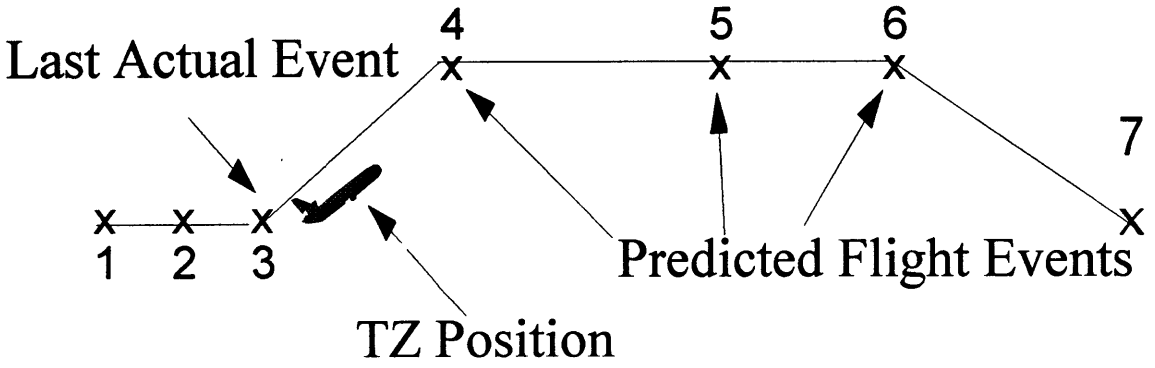


Fig. 2.2.1 Examples of TZ Processing

2.2.3.3 Position Update Processing

The position update messages(TZ) contain the tracked position and groundspeed for an active flight. The ETMS uses the TZ data to extrapolate the predicted time and speed of future events and to interpolate the actual time of any immediate past events. (Since the data is received at 5 minute intervals, it is necessary to interpolate to estimate the "actual" time for each event after it has been passed.)

An example of TZ processing is shown in Fig. 2.2.1. We just take the TZ processing whenever the TZ position is within 15 miles to the flight path. The TZ processing finds the last actual event (closest previous event , event 3 in this case) and estimates the time of that event based on the distance from the TZ position to the event, the TZ speed over ground and the TZ time. Then the TZ processing uses the speed over ground to update cruising speed. Finally, the TZ processing re-computes the times for the predicted events in the manner described in section 2.2.3.2.

Chapter 3

Methodology Analysis

3.1 Introduction

This chapter explains the methodology used in the thesis. Section 3.2 describes how to use the position update (TZ) points we picked from the files: Den_srf, Mco_srf, Msp_srf, and Phx_srf to draw the plots between the EFTA errors with Time-to-go (T). Section 3.3 shows plots of EFTA errors, $\sigma(T)$, for different discrete time-to-go values T (=30,60,90 mins, etc.) from respective city. Section 3.4 draws the plots of $\sigma(T)$'s variation with time to go T. We consider flights by jet aircraft as well as propeller aircraft in the above analysis.

3.2 ETA Errors versus Time-to-go (T)

3.2.1 Denver(DEN)

In the Den_srf file (refer to the attached sample Table3.2.1), we just consider the TZ points and AZ point. We define

Time-to-go(T)=EFTA(AZ)-Message Time(i)

EFTA Error=EFTA(i)-EFTA(AZ)

i = all the sample points we chose (it is necessary to eliminate all messages which are not TZ points)

These calculations mean that a positive EFTA Error indicates that the estimate at T was later than the actual time; a negative value indicates that the estimate at T was earlier than the actual time.

There are 114 jet flights and 28 prop flights we chose from the Den_srf file. Figs. 3.2.1a to 3.2.1f are samples of the plots for the EFTA errors versus Time -to-go T.

3.2.2 Orlando(MCO)

In the Mco_srf file (refer to the attached sample Table3.2.2), there are 65 jet flights and 16 prop flights we chose from the Den_srf file. Figs.3.2.2a to 3.2.c are samples of the plots for the EFTA errors versus Time -to-go T.

3.2.3 Minneapolis(MSP)

In the Msp_srf file (refer to the attached sample Table3.3), there are 81 jet flights and 40 prop flights we chose from the Den_srf file. Figs.3.2.3a to 3.2.3e are samples of the plots for the EFTA errors versus Time -to-go T.

3.2.4 Phoenix(PHX)

In the Phx_srf file (refer to the attached sample Table3.4), there are 60 jet flights and 7 prop flights we chose from the Den_srf file. Figs.3.2.4a to 3.2.4d are samples of the plots for the EFTA errors versus Time -to-go T.

3.3 Distribution of EFTA Errors at Different Time-to-go

We use the data from section 3.2. We choose EFTA error values from the TZ points closet to T (=30,60.90 mins, etc.) The following definitions are needed for plotting the distribution of ETA error in different time periods.

Sample Mean=$\bar{x}=\sum_{i=1}\frac{NiXi}{Ni}$ Ni=Number (Eqn3.1)

Xi=EFTA Value

Sample Variance=$\bar{S}=\frac{\sum\left(Xi-\bar{x}\right)^2}{n}$ (Eqn3.2)

Standard Deviation=$\sigma^2=E\left[\left(X-\bar{x}\right)\right]^2$ (Eqn3.3)

3.3.1 Denver(DEN)

We use the methodology mentioned in section 3.2, section 3.3, and Eqns. 3.1 to 3.3 to evaluate all the data we got in section 3.1. Tables 3.3.1a to 3.3.1h and Figs. 3.3.1a

to 3.3.1h are the chosen sample EFTA error points and Weight versus EFTA error plots, respectively.

3.3.2 Orlando (MCO)

Tables 3.3.2a to 3.3.2e and Figs. 3.3.2a to 3.3.2e are the chosen sample EFTA error points and Weight versus EFTA error plots, respectively.

3.3.3 Minneapolis(MSP)

Tables 3.3.3a to 3.3.3g and Figs.3.3.3a to 3.3.3g are the chosen sample EFTA error points and Weight versus EFTA error plots, respectively.

3.3.4 Phoenix(PHX)

Tables 3.3.4a to 3.3.4e and Figs. 3.3.4a to 3.3.4e are the chosen sample EFTA error points and Weight versus EFTA error plots, respectively.

3.3.5 All Cities

Tables 3.3.5a to 3.3.5g and Fig 3.3.5a to 3.3.5g are the chosen sample EFTA error points and Weight versus EFTA error plots, respectively.

3.4 Standard Deviation versus Time-to-go

In this section, we use the results we got in section 3.3. Tables 3.4a to 3.4b and Figs.3.4a to 3.4b are the σ's variation with Time to Go (T=30,60,90 mins, etc.) for Jets as well as Props. As it can be seen, there is a slight downward trend in uncertainty for estimating Arrival Fix times as Time-to-go decreases.

Flight No	Origin	Destination	Message Time	NAS Message	Arrival Fix	EFTA	TTP	ETD	ETA	A/C	Class	Category
AAL169	DFW	DEN	11:46	FZ	RAMAH	14:28	6	13:11	14:42	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:21	DZ	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:22	TZ	RAMAH	14:35	6	13:22	14:49	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:30	FA	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:32	FA	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:32	TZ	RAMAH	14:36	6	13:22	14:50	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:37	TZ	RAMAH	14:40	6	13:22	14:54	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:42	TZ	RAMAH	14:38	6	13:22	14:52	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:47	TZ	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:49	UZ	RAMAH	14:38	6	13:22	14:52	MD80	LARG	CIV/JET
AAL169	DFW	DEN	13:56	TZ	RAMAH	14:41	6	13:22	14:55	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:01	TZ	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:06	TZ	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:09	FA	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:11	TZ	RAMAH	14:39	6	13:22	14:54	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:15	TZ	RAMAH	14:37	6	13:22	14:51	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:16	TZ	RAMAH	14:38	6	13:22	14:52	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:18	UZ	RAMAH	14:37	6	13:22	14:51	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:20	TZ	RAMAH	14:36	6	13:22	14:50	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:25	TZ	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:30	TZ	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:35	TZ	RAMAH	14:39	6	13:22	14:53	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:40	TZ	RAMAH	14:41	6	13:22	14:55	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:45	TZ	RAMAH	14:43	4	13:22	14:57	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:50	TZ	RAMAH	14:43	4	13:22	14:59	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:55	TZ	RAMAH	14:43	4	13:22	14:59	MD80	LARG	CIV/JET
AAL169	DFW	DEN	14:58	AZ	RAMAH	14:43	4	13:22	14:45	MD80	LARG	CIV/JET

Table3.2.1 Data Sample-DEN Flights

Flight No	Origin	Destination	Message Time	NAS Message	Arrival Fix	EFTA	TTP	ETD	ETA	A/C	Class	Category
AAL174	RDU	MCO	13:56	FZ	LAMMA	16:27	6	15:18	16:38	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	15:39	DZ	LAMMA	16:49	6	15:40	17:00	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	15:41	TZ	LAMMA	16:45	6	15:40	16:56	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	15:47	TZ	LAMMA	16:46	6	15:40	16:57	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	15:52	UZ	LAMMA	16:39	6	15:40	16:50	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	15:54	TZ	LAMMA	16:47	6	15:40	16:58	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	15:59	TZ	LAMMA	16:43	6	15:40	16:54	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:04	TZ	LAMMA	16:45	6	15:40	16:56	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:09	TZ	LAMMA	16:44	6	15:40	16:55	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:14	TZ	LAMMA	16:44	6	15:40	16:55	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:20	TZ	LAMMA	16:45	6	15:40	16:56	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:24	TZ	LAMMA	16:45	6	15:40	16:56	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:29	TZ	LAMMA	16:43	6	15:38	16:54	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:35	TZ	LAMMA	16:44	6	15:38	16:55	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:39	TZ	LAMMA	16:44	6	15:38	16:55	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:45	TZ	LAMMA	16:46	6	15:38	16:57	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	16:54	TZ	LAMMA	17:01	4	15:38	17:12	DC1	HEAV	CIV/JET
AAL174	RDU	MCO	17:02	AZ	LAMMA	17:01	4	15:38	16:53	DC1	HEAV	CIV/JET

Table3.2.2 Data Sample-MCO Flights

Flight N	Origin	Destination	Message Time	NAS Message	Arrival Fix	EFTA	TTP	ETD	ETA	A/C	Class	Category
AAL832	DFW	MSP	12:51	FZ	MEINZ	15:56	6	14:17	16:10	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:26	DZ	MEINZ	16:06	6	14:27	16:20	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:36	FA	MEINZ	16:06	6	14:27	16:20	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:36	TZ	MEINZ	16:05	6	14:27	16:17	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:41	TZ	MEINZ	16:02	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:46	TZ	MEINZ	16:02	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:47	UZ	MEINZ	16:02	6	14:27	16:16	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:50	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	14:55	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:00	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:05	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:10	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:15	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:20	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:25	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:26	UZ	MEINZ	16:03	6	14:27	16:17	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:27	TZ	MEINZ	16:03	6	14:27	16:17	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:32	TZ	MEINZ	16:03	6	14:27	16:17	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:37	TZ	MEINZ	16:03	6	14:27	16:17	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:42	TZ	MEINZ	16:01	6	14:27	16:14	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:47	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:52	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	15:57	TZ	MEINZ	16:03	6	14:27	16:15	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	16:02	TZ	MEINZ	16:04	6	14:27	16:16	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	16:07	TZ	MEINZ	16:05	5	14:27	16:17	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	16:12	TZ	MEINZ	16:05	5	14:27	16:17	MD8	LARGE	CIV/JET
AAL832	DFW	MSP	16:18	AZ	MEINZ	16:05	5	14:27	16:09	MD8	LARGE	CIV/JET

Table3.2.3 Data Sample-MSP Flights

Flight No	Origin	Destination	Message Time	NAS Message	Arrival Fix	EFTA	TTP	ETD	ETA	A/C	Class	Category
AAL475	DFW	PHX	14:13	FZ	TOTEC	17:33	6	15:39	17:45	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	15:51	DZ	TOTEC	17:46	6	15:52	17:58	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	15:55	TZ	TOTEC	17:44	6	15:52	17:53	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:00	TZ	TOTEC	17:44	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:05	TZ	TOTEC	17:57	6	15:52	18:07	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:10	TZ	TOTEC	17:49	6	15:52	17:59	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:15	TZ	TOTEC	17:50	6	15:52	18:00	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:20	TZ	TOTEC	17:48	6	15:52	17:58	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:25	TZ	TOTEC	17:47	6	15:52	17:57	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:30	TZ	TOTEC	17:46	6	15:52	17:56	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:35	TZ	TOTEC	17:46	6	15:52	17:56	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:40	TZ	TOTEC	17:46	6	15:52	17:56	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:42	UZ	TOTEC	17:45	6	15:52	17:57	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:45	FA	TOTEC	17:46	6	15:52	17:58	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:45	TZ	TOTEC	17:46	6	15:52	17:56	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:50	TZ	TOTEC	17:45	6	15:52	17:56	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	16:55	TZ	TOTEC	17:46	6	15:52	17:57	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:00	TZ	TOTEC	17:46	6	15:52	17:57	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:05	TZ	TOTEC	17:44	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:10	TZ	TOTEC	17:43	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:15	TZ	TOTEC	17:43	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:20	TZ	TOTEC	17:43	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:25	TZ	TOTEC	17:43	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:30	TZ	TOTEC	17:44	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:35	TZ	TOTEC	17:44	6	15:52	17:55	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:40	TZ	TOTEC	17:43	6	15:52	17:54	MD80	LARGE	CIV/JET
AAL475	DFW	PHX	17:56	AZ	TOTEC	17:41	5	15:52	17:50	MD80	LARGE	CIV/JET

Table3.2.4 Data Sample-PHX Flights

Number	Item	Ratio
1	-16	0.00877193
0	-15	0
1	-14	0.00877193
1	-13	0.00877193
0	-12	0
1	-11	0.00877193
4	-10	0.035087719
1	-9	0.00877193
3	-8	0.026315789
1	-7	0.00877193
3	-6	0.026315789
0	-5	0
5	-4	0.043859649
2	-3	0.01754386
6	-2	0.052631579
13	-1	0.114035088
31	0	0.271929825
22	1	0.192982456
9	2	0.078947368
3	3	0.026315789
3	4	0.026315789
0	5	0
0	6	0
2	7	0.01754386
0	8	0
1	9	0.00877193
0	10	0
0	11	0
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
0	22	0
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
1	29	0.00877193
Mean	-0.7895	
Standard Deviation	4.946150933	
Variance	24.46440905	
Total#	114	

Table3.3.1a Didtribution of Errors in EFTA at 30min-DEN Flights

Number	Item	Ratio
1	-15	0.009803922
1	-14	0.009803922
1	-13	0.009803922
0	-12	0
1	-11	0.009803922
1	-10	0.009803922
2	-9	0.019607843
2	-8	0.019607843
4	-7	0.039215686
6	-6	0.058823529
1	-5	0.009803922
2	-4	0.019607843
4	-3	0.039215686
9	-2	0.088235294
6	-1	0.058823529
18	0	0.176470588
11	1	0.107843137
12	2	0.117647059
5	3	0.049019608
1	4	0.009803922
6	5	0.058823529
1	6	0.009803922
3	7	0.029411765
1	8	0.009803922
1	9	0.009803922
0	10	0
0	11	0
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
1	22	0.009803922
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
0	29	0
0	30	0
0	31	0
1	32	0.009803922
Mean	-0.2745	
Standard Deviation	6.060410161	
Variance	36.72857132	
Total#	102	

Table3.3.1bDistribution of Errors in EFTA at 60min-DEN Flights

Number	Item	Ratio
1	-16	0.016666667
0	-15	0
0	-14	0
0	-13	0
0	-12	0
1	-11	0.016666667
1	-10	0.016666667
1	-9	0.016666667
4	-8	0.066666667
0	-7	0
4	-6	0.066666667
0	-5	0
7	-4	0.116666667
5	-3	0.083333333
3	-2	0.05
7	-1	0.116666667
3	0	0.05
4	1	0.066666667
3	2	0.05
3	3	0.05
5	4	0.083333333
4	5	0.066666667
0	6	0
0	7	0
1	8	0.016666667
2	9	0.033333333
0	10	0
0	11	0
0	12	0
1	13	0.016666667
Mean	-1	
Standard Deviation	5.310367219	
Variance	28.2	
Total#	60	

Table3.3.1c Distribution of Errors in EFTA at 90min-DEN Flights

Number	Item	Ratio
1	-19	0.03030303
0	-18	0
1	-17	0.03030303
0	-16	0
1	-15	0.03030303
0	-14	0
0	-13	0
0	-12	0
0	-11	0
0	-10	0
1	-9	0.03030303
2	-8	0.060606061
1	-7	0.03030303
0	-6	0
2	-5	0.060606061
2	-4	0.060606061
3	-3	0.090909091
2	-2	0.060606061
2	-1	0.060606061
1	0	0.03030303
3	1	0.090909091
2	2	0.060606061
1	3	0.03030303
0	4	0
0	5	0
1	6	0.03030303
0	7	0
2	8	0.060606061
0	9	0
0	10	0
3	11	0.090909091
0	12	0
0	13	0
1	14	0.03030303
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
0	22	0
1	23	0.03030303
Mean	-0.424	
Standard Deviation	8.73527747	
Variance	76.30507248	
Total#	33	

Table3.3.1d Distribution of Errors in EFTA at 120min-DEN Flights

Number	Item	Ratio
1	-10	0.047619048
0	-9	0
0	-8	0
0	-7	0
0	-6	0
0	-5	0
1	-4	0.047619048
1	-3	0.047619048
1	-2	0.047619048
2	-1	0.095238095
0	0	0
1	1	0.047619048
1	2	0.047619048
2	3	0.095238095
2	4	0.095238095
0	5	0
1	6	0.047619048
1	7	0.047619048
2	8	0.095238095
0	9	0
0	10	0
3	11	0.142857143
0	12	0
0	13	0
1	14	0.047619048
0	15	0
0	16	0
0	17	0
0	18	0
1	19	0.047619048
Mean	4.33	
Standard deviation	6.635642096	
Variance	44.03174603	
TOTAL#	21	

Table3.3.1e Distribution of Errors in EFTA at 150min-DEN Flights

Number	Item	Ratio
1	-24	0.0625
0	-23	0
0	-22	0
0	-21	0
0	-20	0
0	-19	0
1	-18	0.0625
0	-17	0
0	-16	0
0	-15	0
0	-14	0
0	-13	0
0	-12	0
0	-11	0
1	-10	0.0625
1	-9	0.0625
1	-8	0.0625
0	-7	0
0	-6	0
1	-5	0.0625
0	-4	0
1	-3	0.0625
0	-2	0
0	-1	0
2	0	0.125
0	1	0
1	2	0.0625
1	3	0.0625
0	4	0
1	5	0.0625
0	6	0
0	7	0
1	8	0.0625
0	9	0
0	10	0
0	11	0
0	12	0
0	13	0
0	14	0
1	15	0.0625
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
0	22	0
0	23	0
0	24	0
0	25	0
0	26	0
1	27	0.0625
0	28	0
0	29	0
0	30	0
1	31	0.0625
Mean	0.875	
Standard Deviation	14.10618216	
Variance	198.984375	
Total#	16	

Table3.3.1f Distribution of Errors in EFTA at 180min-DEN Flights

Num#	Item	Ratio
1	-8	0.035714286
0	-7	0
0	-6	0
1	-5	0.035714286
3	-4	0.107142857
1	-3	0.035714286
2	-2	0.071428571
2	-1	0.071428571
3	0	0.107142857
4	1	0.142857143
2	2	0.071428571
3	3	0.107142857
2	4	0.071428571
1	5	0.035714286
0	6	0
1	7	0.035714286
0	8	0
0	9	0
1	10	0.035714286
0	11	0
1	12	0.035714286
Mean	0.2928	
Standard Deviation	4.40210789	
Variance	19.37855387	
Total#	28	

Table 3.3.1g Distribution of Errors in EFTA at 30min-DEN Flights(Prop)

Num#	Item	Ratio
1	-14	0.1
0	-13	0
0	-12	0
0	-11	0
0	-10	0
0	-9	0
0	-8	0
0	-7	0
0	-6	0
2	-5	0.2
1	-4	0.1
0	-3	0
0	-2	0
0	-1	0
0	0	0
1	1	0.1
1	2	0.1
0	3	0
0	4	0
0	5	0
0	6	0
0	7	0
0	8	0
0	9	0
1	10	0.1
0	11	0
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
1	17	0.1
0	18	0
0	19	0
1	20	0.1
1	21	0.1
Mean	4.3	
Standard Deviation	11.45469336	
Variance	131.21	
Total#	10	

Table3.3.1h Distribution of Errors in EFTA at 60min-DEN Flights(Prop)

Num#	Item	Ratio
1	-18	0.015625
0	-17	0
1	-16	0.015625
3	-15	0.046875
2	-14	0.03125
0	-13	0
0	-12	0
0	-11	0
0	-10	0
0	-9	0
0	-8	0
0	-7	0
0	-6	0
1	-5	0.015625
0	-4	0
1	-3	0.015625
3	-2	0.046875
5	-1	0.078125
6	0	0.09375
11	1	0.171875
12	2	0.1875
10	3	0.15625
5	4	0.078125
2	5	0.03125
0	6	0
1	7	0.015625
Mean	-0.375	
Standard Deviation	5.613877893	
Variance	31.515625	
Total#	64	

Table3.3.2a Distribution of Errors in EFTA at 30min-MCO Flights

Num#	Item	Ratio
1	-18	0.017857143
0	-17	0
2	-16	0.035714286
1	-15	0.017857143
1	-14	0.017857143
3	-13	0.053571429
0	-12	0
0	-11	0
1	-10	0.017857143
1	-9	0.017857143
0	-8	0
1	-7	0.017857143
0	-6	0
0	-5	0
0	-4	0
3	-3	0.053571429
1	-2	0.017857143
7	-1	0.125
5	0	0.089285714
7	1	0.125
4	2	0.071428571
8	3	0.142857143
5	4	0.089285714
1	5	0.017857143
1	6	0.017857143
3	7	0.053571429
Mean	-1.268	
Standard Deviation	6.443382342	
Variance	41.517176	
Total#	56	

Table3.3.2b Distribution of Errors in EFTA at 60min-MCO Flights

Num#	Item	Ratio
1	-16	0.022222222
0	-15	0
0	-14	0
1	-13	0.022222222
0	-12	0
1	-11	0.022222222
1	-10	0.022222222
0	-9	0
1	-8	0.022222222
1	-7	0.022222222
3	-6	0.066666667
0	-5	0
1	-4	0.022222222
0	-3	0
1	-2	0.022222222
2	-1	0.044444444
3	0	0.066666667
1	1	0.022222222
1	2	0.022222222
3	3	0.066666667
4	4	0.088888889
3	5	0.066666667
4	6	0.088888889
4	7	0.088888889
2	8	0.044444444
2	9	0.044444444
1	10	0.022222222
0	11	0
1	12	0.022222222
1	13	0.022222222
0	14	0
1	15	0.022222222
0	16	0
0	17	0
1	18	0.022222222
Mean	2.355	
Standard Deviation	7.306661915	
Variance	53.38730833	
Total#	45	

Table3.3.2c Distribution of Errors in EFTA at 90min-MCO Flights

Num#	Item	Ratio
1	-19	0.04
3	-18	0.12
1	-17	0.04
0	-16	0
1	-15	0.04
2	-14	0.08
1	-13	0.04
1	-12	0.04
2	-11	0.08
0	-10	0
0	-9	0
2	-8	0.08
2	-7	0.08
2	-6	0.08
0	-5	0
1	-4	0.04
1	-3	0.04
0	-2	0
1	-1	0.04
0	0	0
1	1	0.04
0	2	0
0	3	0
1	4	0.04
0	5	0
1	6	0.04
0	7	0
0	8	0
1	9	0.04
Mean	-8.4	
Standard deviation	7.714920609	
Variance	59.52	
Total#	25	

Table3.3.2d Distribution of Errors in EFTA at 120min-MCO Flights

Num#	Item	Ratio
1	-5	0.047619048
0	-4	0
1	-3	0.047619048
4	-2	0.19047619
2	-1	0.095238095
4	0	0.19047619
1	1	0.047619048
5	2	0.238095238
3	3	0.142857143
Mean	0.095	
Standard Deviation	2.180110034	
Variance	4.752879762	
Total#	21	

Table3.3.2e Distribution of Errors in EFTA at 30min-MCO Flights(Prop)

Number#	Item	Ratio
1	-8	0.0125
0	-7	0
2	-6	0.025
7	-5	0.0875
4	-4	0.05
9	-3	0.1125
15	-2	0.1875
14	-1	0.175
11	0	0.1375
8	1	0.1
4	2	0.05
2	3	0.025
1	4	0.0125
0	5	0
2	6	0.025
Mean	-1.3	
Standard Deviatio	2.561249695	
Variance	6.56	
Total #	80	

Table3.3.3a Distribution of Errors in EFTA at 30min-MSP Flights

Number#	Item	Ratio
2	-7	0.037735849
2	-6	0.037735849
4	-5	0.075471698
4	-4	0.075471698
6	-3	0.113207547
13	-2	0.245283019
4	-1	0.075471698
5	0	0.094339623
5	1	0.094339623
3	2	0.056603774
4	3	0.075471698
0	4	0
1	5	0.094339623
Mean	-1.169811321	
Standard Deviatio	3.219843246	
Variance	10.36739053	
Total #	53	

Table3.3.3b Distribution of Errors in EFTA at 60min-MSP Flights

Number#	Item	Ratio
1	-8	0.035714286
1	-7	0.035714286
1	-6	0.035714286
0	-5	0
1	-4	0.035714286
1	-3	0.035714286
1	-2	0.035714286
1	-1	0.035714286
6	0	0.214285714
3	1	0.107142857
1	2	0.035714286
0	3	0
2	4	0.071428571
0	5	0
1	6	0.035714286
1	7	0.035714286
1	8	0.035714286
1	9	0.035714286
2	10	0.071428571
1	11	0.035714286
0	12	0
1	13	0.035714286
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
1	20	0.035714286
Mean	2.714285714	
Standard Deviation	6.357544129	
Variance	40.41836735	
Total#	28	

Table3.3.3c Distribution of Errors in EFTA at 90min-MSP Flights

Number#	Item	Ratio
1	-13	0.055555556
2	-12	0.111111111
0	-11	0
0	-10	0
0	-9	0
0	-8	0
0	-7	0
1	-6	0.055555556
1	-5	0.055555556
0	-4	0
1	-3	0.055555556
0	-2	0
2	-1	0.111111111
3	0	0.166666667
1	1	0.055555556
1	2	0.055555556
0	3	0
0	4	0
0	5	0
1	6	0.055555556
1	7	0.055555556
0	8	0
0	9	0
0	10	0
0	11	0
0	12	0
0	13	0
0	14	0
0	15	0
1	16	0.055555556
0	17	0
0	18	0
1	19	0.055555556
1	20	0.055555556
Mean	1	
Standard Deviation	9.480975102	
Variance	89.88888889	
Total#	18	

Table 3.3.3d Distribution of Errors in EFTA at 120min-MSP Flights

Number#	Item	Ratio
1	-10	0.142857143
0	-9	0
0	-8	0
0	-7	0
1	-6	0.142857143
0	-5	0
0	-4	0
0	-3	0
2	-2	0.285714286
0	-1	0
0	0	0
0	1	0
1	2	0.142857143
0	3	0
0	4	0
0	5	0
0	6	0
1	7	0.142857143
0	8	0
0	9	0
1	10	0.142857143
Mean	-0.142857143	
Standard Deviation	6.51215504	
Variance	42.40816327	
Total#	7	

Table3.3.3e Distribution of Errors in EFTA at 150min-MSP Flights

Number#	Item	Ratio
1	-17	0.024390244
0	-16	0
0	-15	0
0	-14	0
0	-13	0
0	-12	0
0	-11	0
0	-10	0
1	-9	0.024390244
0	-8	0
0	-7	0
3	-6	0.073170732
1	-5	0.024390244
1	-4	0.024390244
3	-3	0.073170732
3	-2	0.073170732
4	-1	0.097560976
7	0	0.170731707
4	1	0.0976
3	2	0.0732
1	3	0.0244
5	4	0.1220
1	5	0.0244
2	6	0.0488
0	7	0
0	8	0
1	9	0.0244
Mean	-0.317073171	
Standard Deviatio	4.528710711	
Variance	20.5092207	
Total#	41	

Table3.3.3f Distribution of Errors in EFTA at 30min-MSP Flights(Prop)

Number#	Item	Ratio
1	-15	0.142857143
0	-14	0
0	-13	0
1	-12	0.142857143
0	-11	0
0	-10	0
0	-9	0
0	-8	0
0	-7	0
0	-6	0
1	-5	0.142857143
0	-4	0
0	-3	0
1	-2	0.142857143
0	-1	0
1	0	0.142857143
0	1	0
1	2	0.142857143
0	3	0
0	4	0
0	5	0
0	6	0
	7	0
0	8	0
1	9	0.142857143
Mean	-3.285714286	
Standard Deviatio	7.629159956	
Variance	58.20408163	
Total#	7	

Table3.3.3g Distribution of Errors in EFTA at 60min-MSP Flights(Prop)

Number#	Item	Ratio
2	-3	0.0339
2	-2	0.0339
4	-1	0.0678
11	0	0.1864
7	1	0.1186
10	2	0.1695
4	3	0.0678
6	4	0.1017
6	5	0.1017
0	6	0.0000
0	7	0.0000
0	8	0.0000
1	9	0.0169
0	10	0
2	11	0.0339
1	12	0.0169
0	13	0.0000
0	14	0.0000
1	15	0.0169
0	16	0.0000
1	17	0.0169
0	18	0.0000
1	19	0.0169
Mean	2.9322	
Standard Deviatio	4.50	
Variance	20.2327	
Total#	59	

Table3.3.4a Distribution of Errors in EFTA at 30min-PHX Flights

Number	Item	Ratio
2	-3	0.1176
0	-2	0.0000
1	-1	0.0588
3	0	0.1765
1	1	0.0588
2	2	0.1176
1	3	0.0588
3	4	0.1765
2	5	0.1176
0	6	0.0000
0	7	0.0000
1	8	0.0588
0	9	0.0000
0	10	0.0000
1	11	0.0588
Mean	2.4706	
Standard Deviation	3.566463942	
Variance	12.71966505	
Total#	17	

Table 3.3.4b Distribution of Errors in EFTA at 60min-PHX Flights

Number	Item	Ratio
1	-5	0.0909
1	-4	0.0909
0	-3	0.0000
0	-2	0.0000
0	-1	0.0000
0	0	0.0000
0	1	0.0000
1	2	0.0909
0	3	0.0000
0	4	0.0000
0	5	0.0000
2	6	0.1818
0	7	0.0000
1	8	0.0909
1	9	0.0909
0	10	0.0000
1	11	0.0909
1	12	0.0909
0	13	0.0000
0	14	0.0000
0	15	0.0000
0	16	0.0000
0	17	0.0000
0	18	0.0000
1	19	0.0909
0	20	0
1	21	0.0909
Mean	7.7273	
Standard Deviation	7.8171	
Variance	61.1070	
Total#	11	

Table3.3.4c Distribution of Errors in EFTA at 90min-PHX Flights

Number#	Item	Ratio
1	7	0.125
2	8	0.25
1	9	0.125
1	10	0.125
0	11	0
0	12	0
1	13	0.125
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
0	22	0
0	23	0
1	24	0.125
0	25	0
0	26	0
0	27	0
0	28	0
0	29	0
1	30	0.125
Mean	13.625	
Standard Deviation	8.045767521	
Variance	64.734375	
Total#	8	

Table3.3.4d Distribution of Errors in EFTA at 120min-PHX Flights

Number	Item	Ratio
1	-3	0.166666667
0	-2	0
2	-1	0.333333333
1	0	0.166666667
0	1	0
1	2	0.166666667
0	3	0
0	4	0
1	5	0.166666667
Mean	0.333333	
Stamdard Deviation	3.049759938	
Variance	9.301035678	
Total#	6	

Table3.3.4e Distribution of Errors in EFTA at 30min-PHX Flights(Prop)

Number#	Item	Ratio
1	-18	0.003154574
0	-17	0
2	-16	0.006309148
3	-15	0.009463722
3	-14	0.009463722
1	-13	0.003154574
0	-12	0
1	-11	0.003154574
4	-10	0.012618297
1	-9	0.003154574
4	-8	0.012618297
1	-7	0.003154574
5	-6	0.015772871
8	-5	0.025236593
9	-4	0.028391167
14	-3	0.044164038
26	-2	0.082018927
36	-1	0.113564669
59	0	0.186119874
48	1	0.151419558
35	2	0.110410095
19	3	0.059936909
15	4	0.047318612
8	5	0.025236593
2	6	0.006309148
3	7	0.009463722
0	8	0
2	9	0.006309148
0	10	0
2	11	0.006309148
1	12	0.003154574
0	13	0
0	14	0
1	15	0.003154574
0	16	0
1	17	0.003154574
0	18	0
1	19	0.003154574
0	20	0
0	21	0
0	22	0
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
1	29	0.003154574
Mean	-0.142	
Standard Deviation	4.779229513	
Variance	22.84103474	
Total#	317	

Table3.3.5a Distribution of Errors in EFTA at 30min-All Citiies Flights

Number#	Item	Ratio
1	-18	0.004385965
0	-17	0
2	-16	0.00877193
2	-15	0.00877193
2	-14	0.00877193
4	-13	0.01754386
0	-12	0
1	-11	0.004385965
2	-10	0.00877193
3	-9	0.013157895
2	-8	0.00877193
7	-7	0.030701754
8	-6	0.035087719
5	-5	0.021929825
6	-4	0.026315789
15	-3	0.065789474
23	-2	0.100877193
18	-1	0.078947368
31	0	0.135964912
24	1	0.105263158
21	2	0.092105263
18	3	0.078947368
9	4	0.039473684
10	5	0.043859649
2	6	0.00877193
6	7	0.026315789
2	8	0.00877193
1	9	0.004385965
0	10	0
1	11	0.004385965
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
1	22	0.004385965
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
0	29	0
0	30	0
0	31	0
1	32	0.004385965
Mean	-0.609	
Standard Deviation	5.511725592	
Variance	30.379119	
Total#	228	

Table3.3.5b Distribution of Errors in EFTA at 60min-All Cities Flights

Number#	Item	Ratio
2	-16	0.013888889
0	-15	0
0	-14	0
1	-13	0.006944444
0	-12	0
2	-11	0.013888889
2	-10	0.013888889
1	-9	0.006944444
6	-8	0.041666667
2	-7	0.013888889
8	-6	0.055555556
1	-5	0.006944444
10	-4	0.069444444
6	-3	0.041666667
5	-2	0.034722222
10	-1	0.069444444
12	0	0.083333333
8	1	0.055555556
6	2	0.041666667
6	3	0.041666667
11	4	0.076388889
7	5	0.048611111
7	6	0.048611111
5	7	0.034722222
5	8	0.034722222
6	9	0.041666667
3	10	0.020833333
2	11	0.013888889
2	12	0.013888889
3	13	0.020833333
0	14	0
1	15	0.006944444
0	16	0
0	17	0
1	18	0.006944444
1	19	0.006944444
1	20	0.006944444
1	21	0.006944444
Mean	1.4375	
Standard Deviation	6.858408009	
Variance	47.03776042	
Total#	144	

Table3.3.5c Distribution of Errors in EFTA at 90min-All Cities Flights

Number#	Item	Ratio
2	-19	0.023809524
3	-18	0.035714286
2	-17	0.023809524
0	-16	0
2	-15	0.023809524
2	-14	0.023809524
2	-13	0.023809524
3	-12	0.035714286
2	-11	0.023809524
0	-10	0
1	-9	0.011904762
4	-8	0.047619048
3	-7	0.035714286
3	-6	0.035714286
3	-5	0.035714286
3	-4	0.035714286
5	-3	0.05952381
2	-2	0.023809524
5	-1	0.05952381
4	0	0.047619048
5	1	0.05952381
3	2	0.035714286
1	3	0.011904762
1	4	0.011904762
0	5	0
3	6	0.035714286
2	7	0.023809524
4	8	0.047619048
2	9	0.023809524
1	10	0.011904762
3	11	0.035714286
0	12	0
1	13	0.011904762
1	14	0.011904762
0	15	0
1	16	0.011904762
0	17	0
0	18	0
1	19	0.011904762
1	20	0.011904762
0	21	0
0	22	0
1	23	0.011904762
1	24	0.011904762
0	25	0
0	26	0
0	27	0
0	28	0
0	29	0
1	30	0.011904762
Mean	-1.154	
Standard Deviation	10.52385943	
Variance	110.7516173	
Total#	84	

Table3.3.5d Distribution of Errors in EFTA at 120min-All Cities Flights

Number#	Item	Ratio
2	-10	0.071428571
0	-9	0
0	-8	0
0	-7	0
1	-6	0.035714286
0	-5	0
1	-4	0.035714286
1	-3	0.035714286
3	-2	0.107142857
2	-1	0.071428571
0	0	0
1	1	0.035714286
2	2	0.071428571
2	3	0.071428571
2	4	0.071428571
0	5	0
1	6	0.035714286
2	7	0.071428571
2	8	0.071428571
0	9	0
1	10	0.035714286
3	11	0.107142857
0	12	0
0	13	0
1	14	0.035714286
0	15	0
0	16	0
0	17	0
0	18	0
1	19	0.035714286
Mean	3.214	
Standard Deviatio	6.883639278	
Variance	47.38448971	
Total#	28	

Table3.3.5e Distribution of Errors in EFTA at 150min-All Cities Flights

Num#	Item	Ratio
1	-17	0.010416667
0	-16	0
0	-15	0
0	-14	0
0	-13	0
0	-12	0
0	-11	0
0	-10	0
1	-9	0.010416667
1	-8	0.010416667
0	-7	0
3	-6	0.03125
3	-5	0.03125
4	-4	0.041666667
6	-3	0.0625
9	-2	0.09375
10	-1	0.104166667
15	0	0.15625
9	1	0.09375
11	2	0.114583333
7	3	0.072916667
7	4	0.072916667
3	5	0.03125
2	6	0.020833333
1	7	0.010416667
0	8	0
1	9	0.010416667
1	10	0.010416667
0	11	0
1	12	0.010416667
Mean	0.166	
Standard Deviation	3.988727115	
Variance	15.909944	
Total#	96	

Table3.3.5f Distribution of Errors in EFTA at 30min-All Cities Flights(Prop

Num#	Item	Ratio
1	-15	0.058823529
1	-14	0.058823529
0	-13	0
1	-12	0.058823529
0	-11	0
0	-10	0
0	-9	0
0	-8	0
0	-7	0
0	-6	0
3	-5	0.176470588
1	-4	0.058823529
0	-3	0
1	-2	0.058823529
0	-1	0
1	0	0.058823529
1	1	0.058823529
2	2	0.117647059
0	3	0
0	4	0
0	5	0
0	6	0
0	7	0
0	8	0
1	9	0.058823529
1	10	0.058823529
0	11	0
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
1	17	0.058823529
0	18	0
0	19	0
1	20	0.058823529
1	21	0.058823529
Mean	1.176	
Standard Deviation	10.72788946	
Variance	115.0876122	
Total#	17	

Table3.3.5g Distribution of Errors in EFTA at 60min-All Cities Flights(Prop)

min/city	All Cities	Denver	Orlando	Phoenix	Minneapolis
0	0	0	0	0	0
30	4.779	4.946	5.613	4.5	2.561
60	5.511	6.06	6.443	3.566	3.219
90	6.858	5.31	7.306	7.817	6.357
120	10.523	8.735	7.714	8.045	9.48
150	6.883	6.635			6.512

Table3.4a Standard Deviation versus Time-to-go(Jet)

min/city	All Cities	Denver	Orlando	Phoenix	Minneapolis
30	3.988	4.402	2.18	3.049	4.528
60	10.727	11.454			7.629

Table3.4b Standard Deviation versus Time-to-go(Prop)

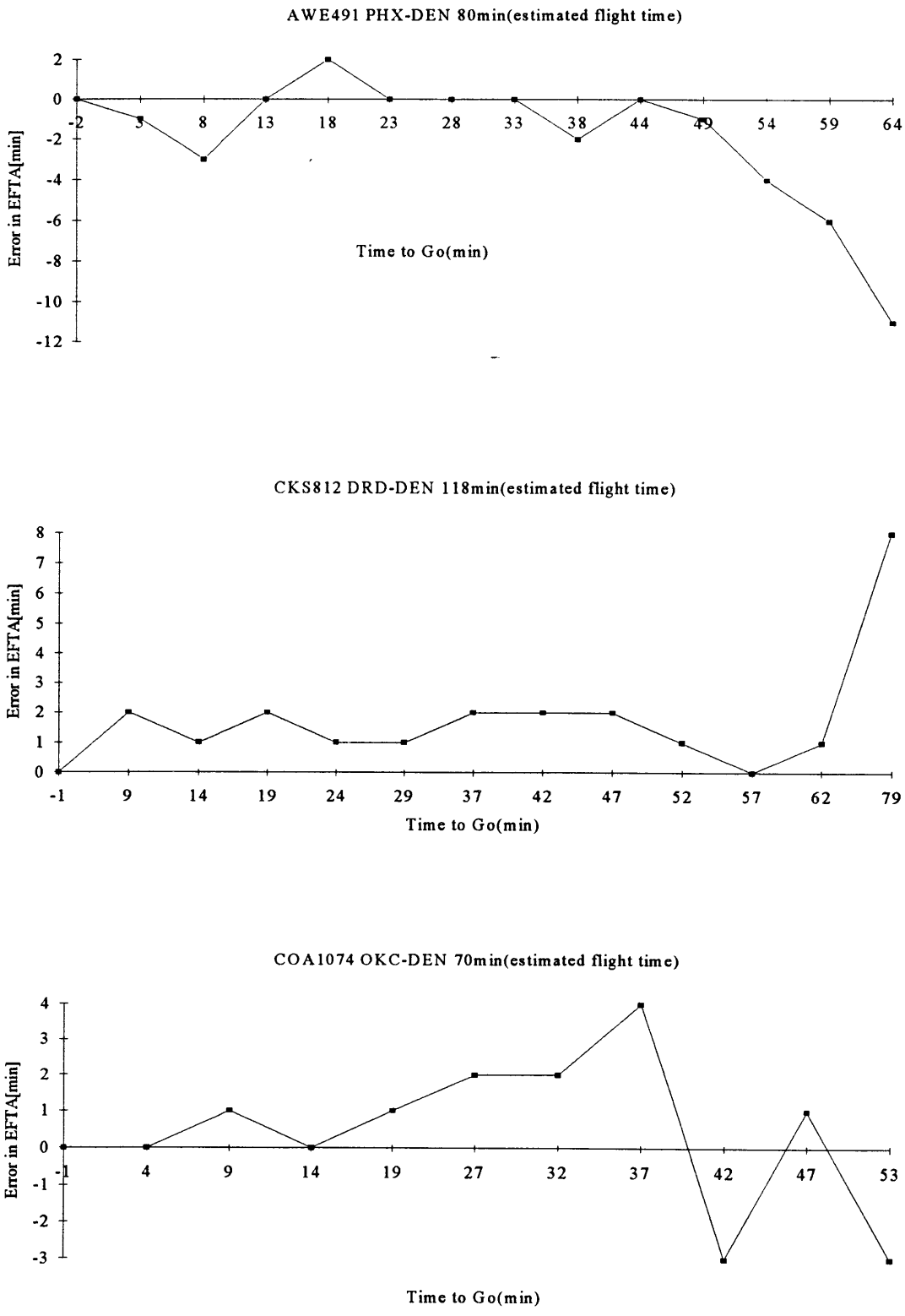


Fig3.2.1a Sample Histories of Estimation Errors(Jet)

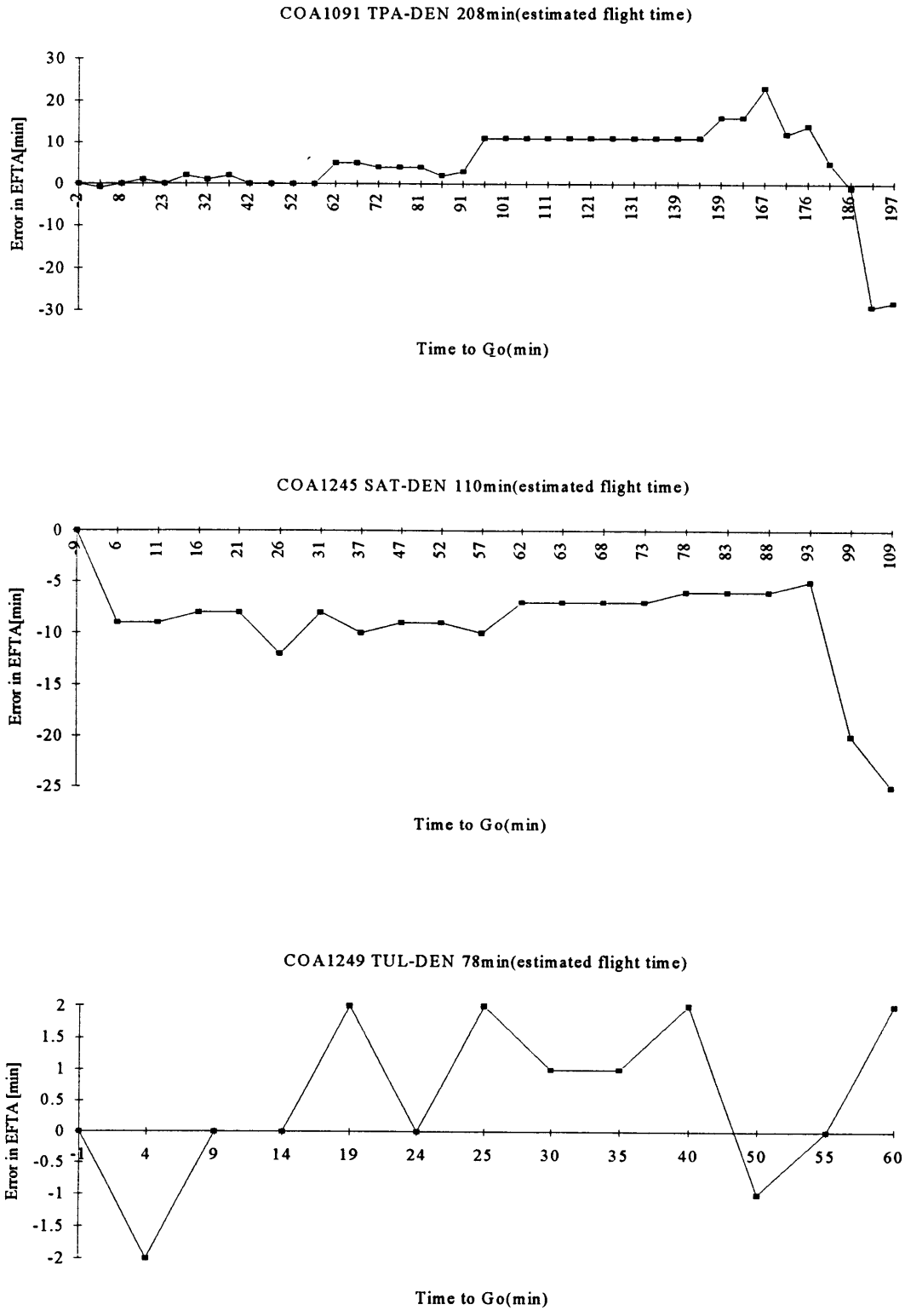
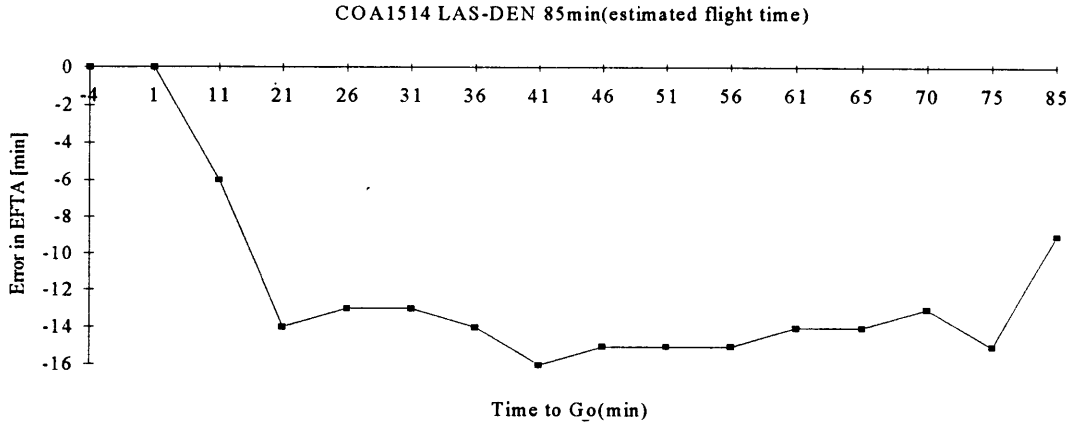
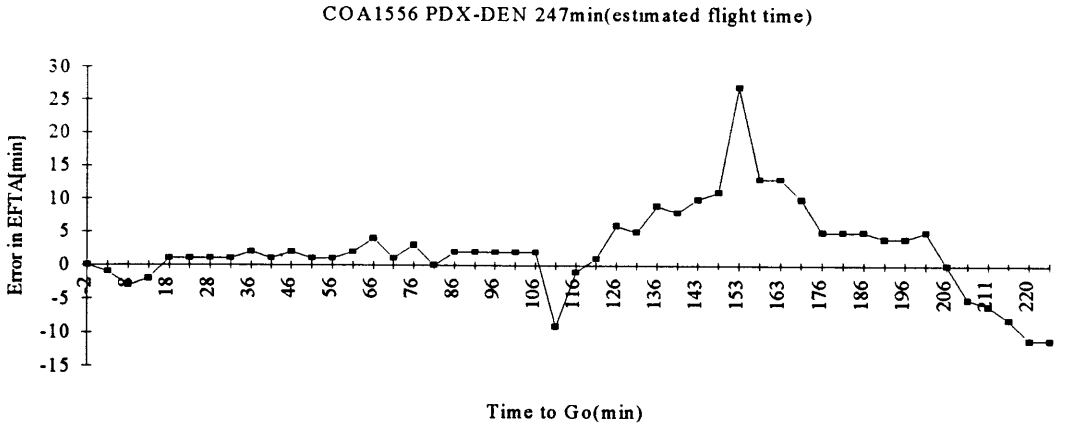


Fig3.2.1b Sample Histories of Estimation Errors(Jet)





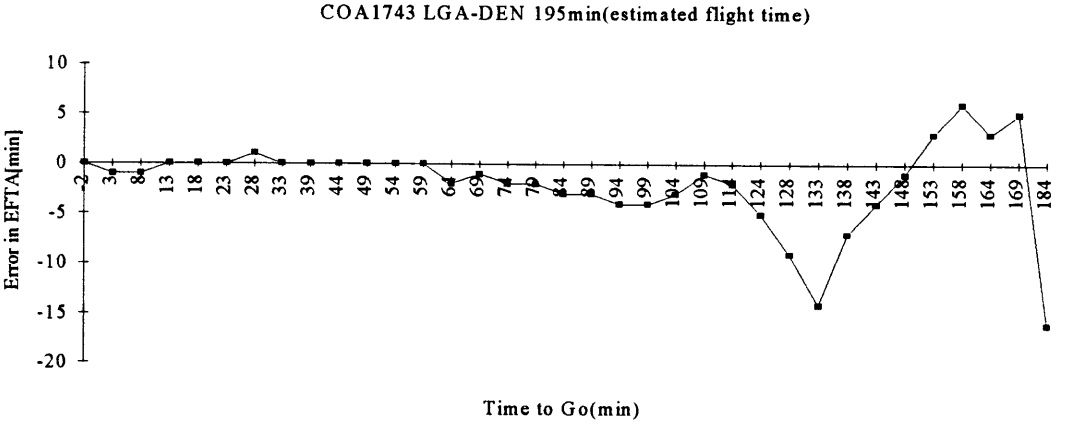
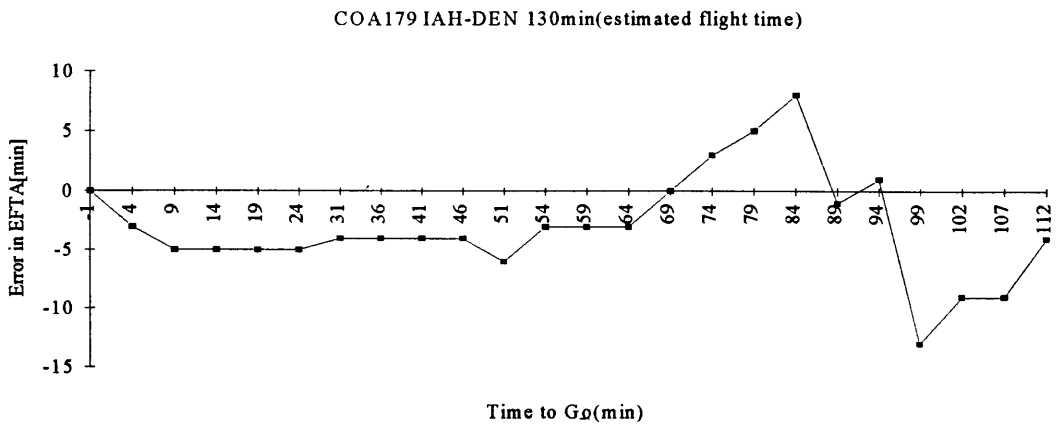
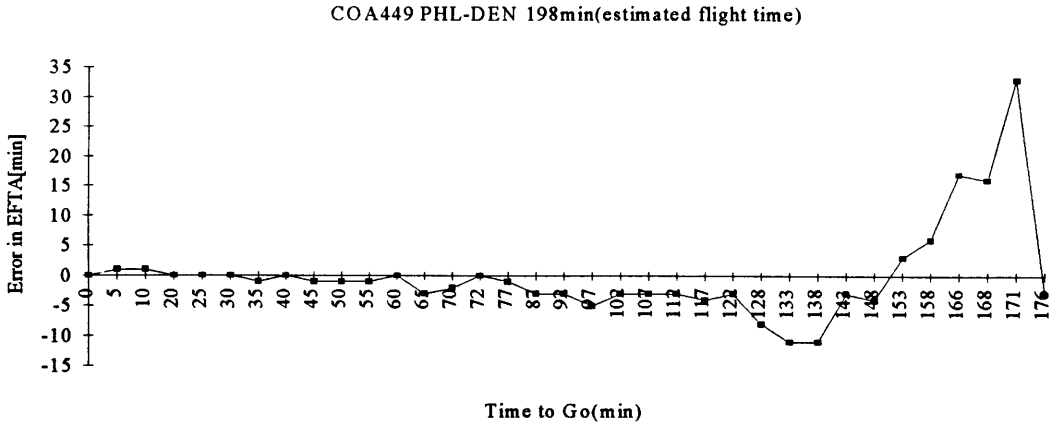


Fig3.2.1c Sample Histories of Estimation Errors(Jet)





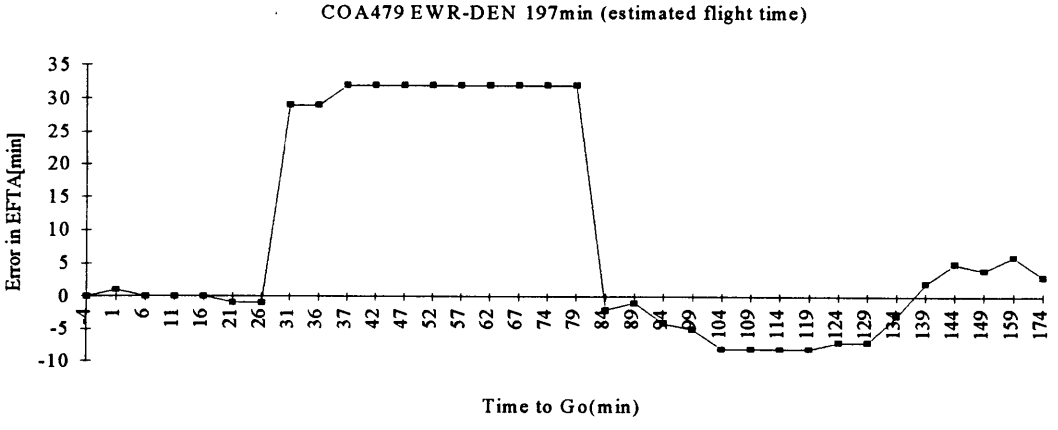
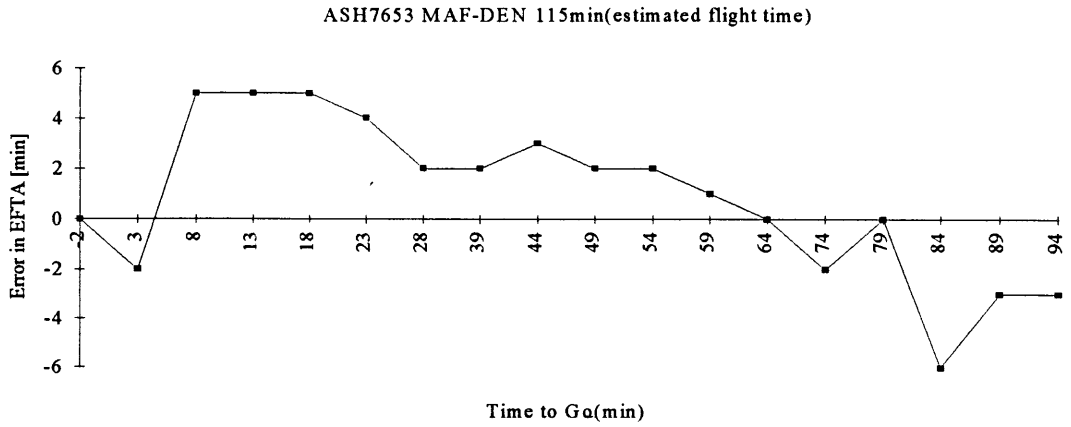
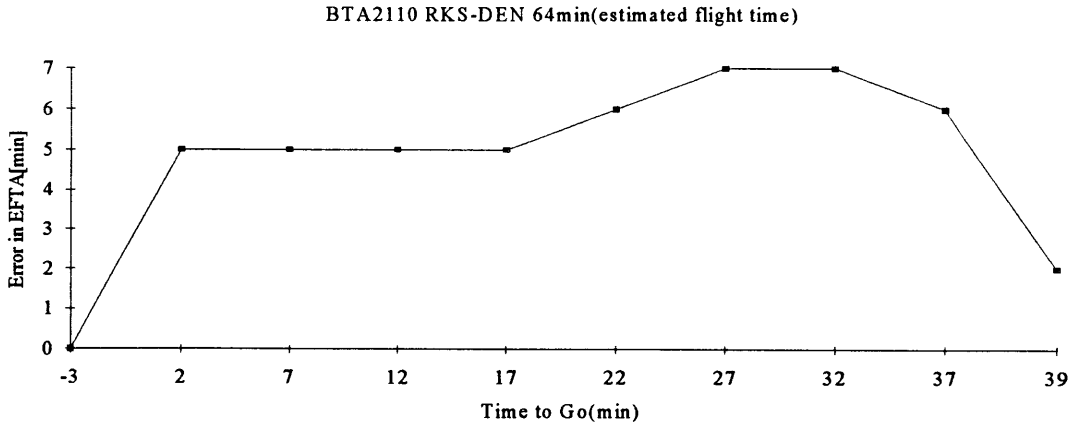


Fig3.2.1d Sample Histories of Estimation Errors(Jet)





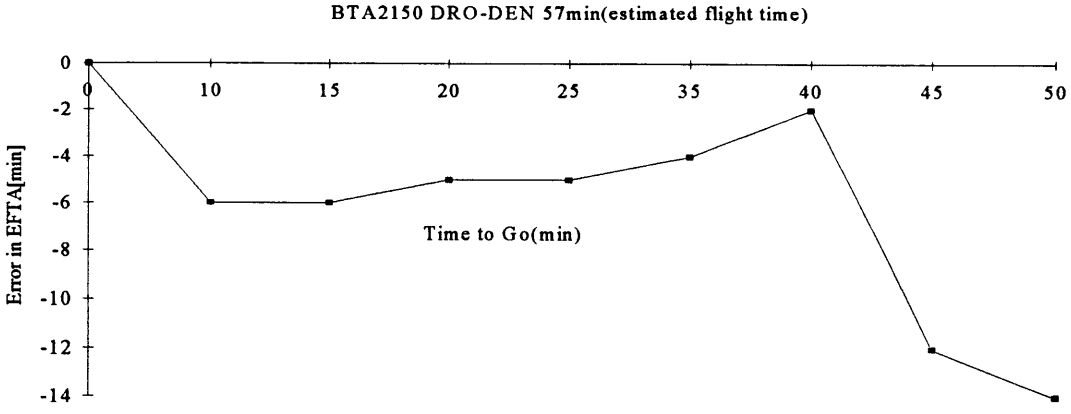
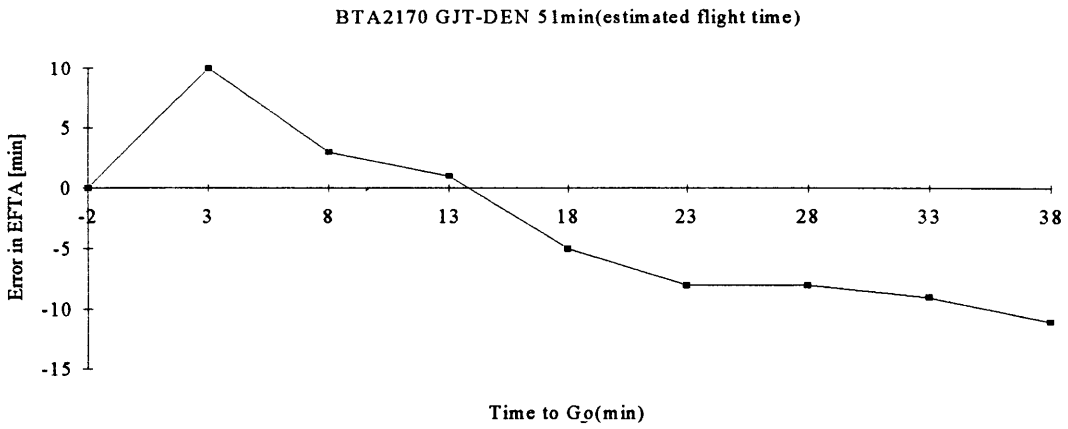
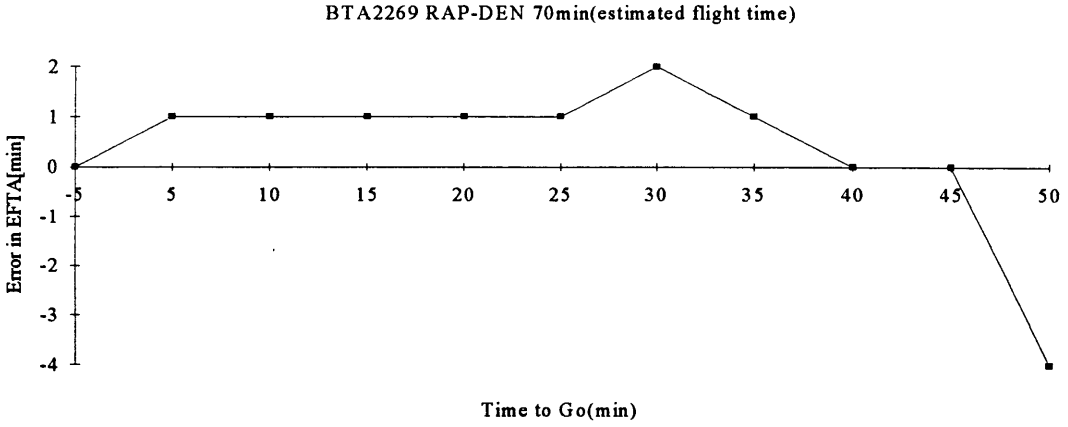


Fig3.2.1e Sample Histories of Estimation Errors(Prop)





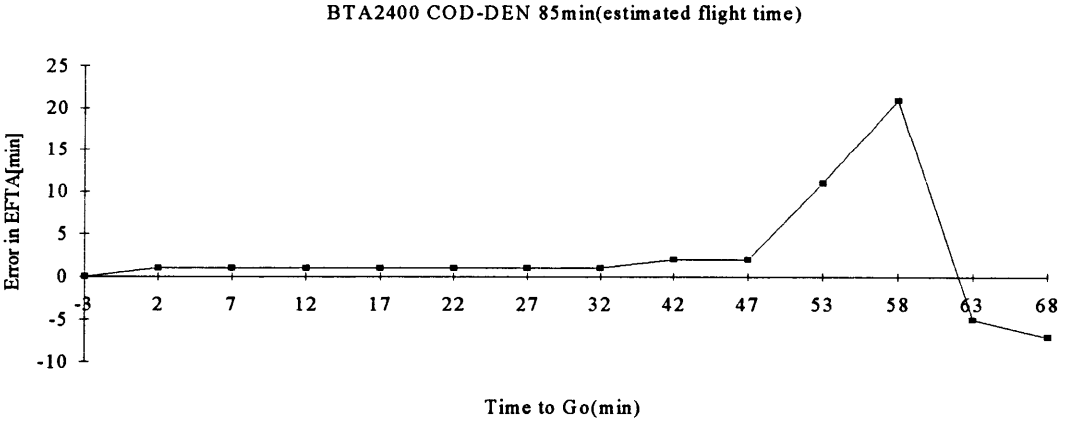
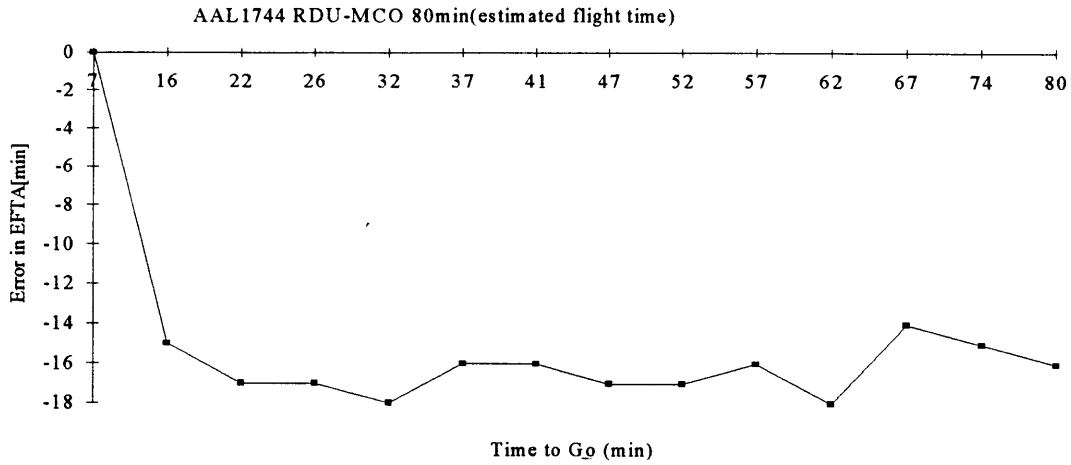
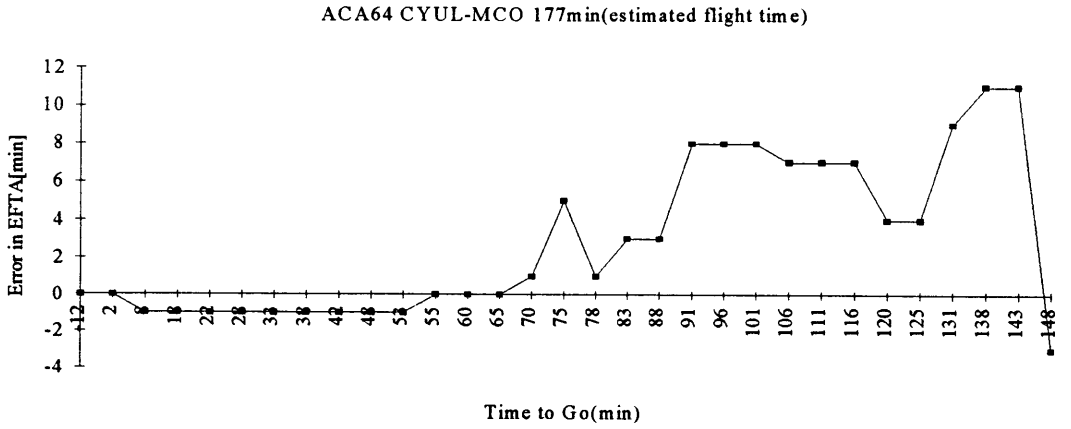


Fig3.2.1f Sample Histories of Estimation Errors(Prop)





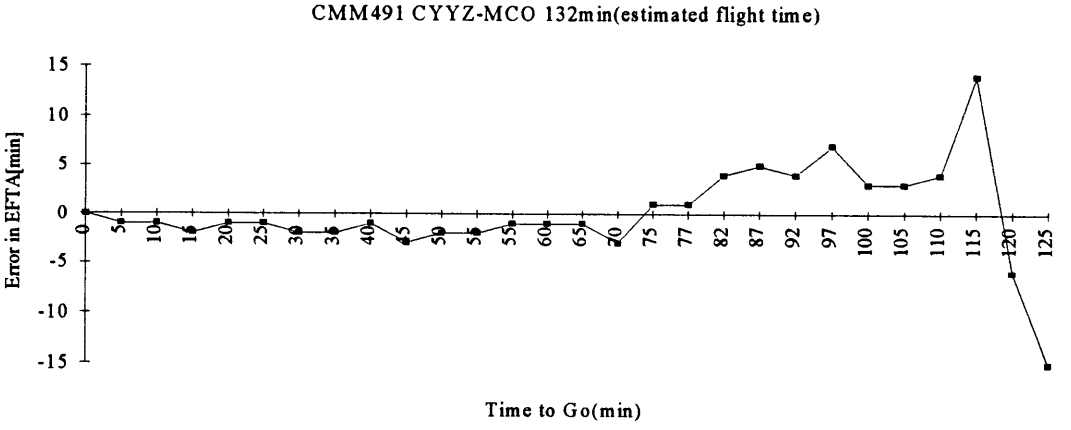


Fig3.2.2a Sample Histories of Estimation Errors(Jet)

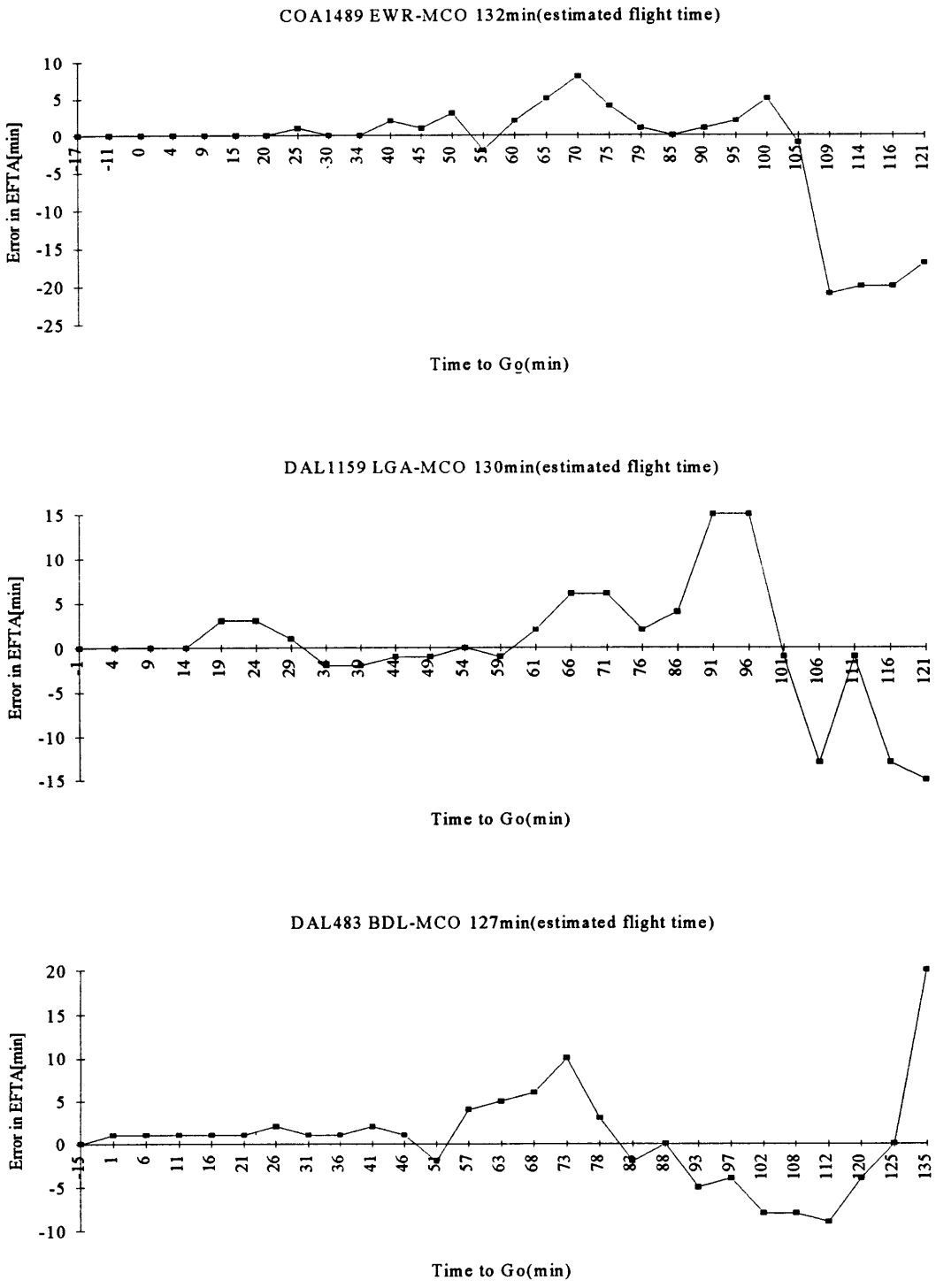


Fig3.2.2b Sample Histories of Estimation Errors(Jet)

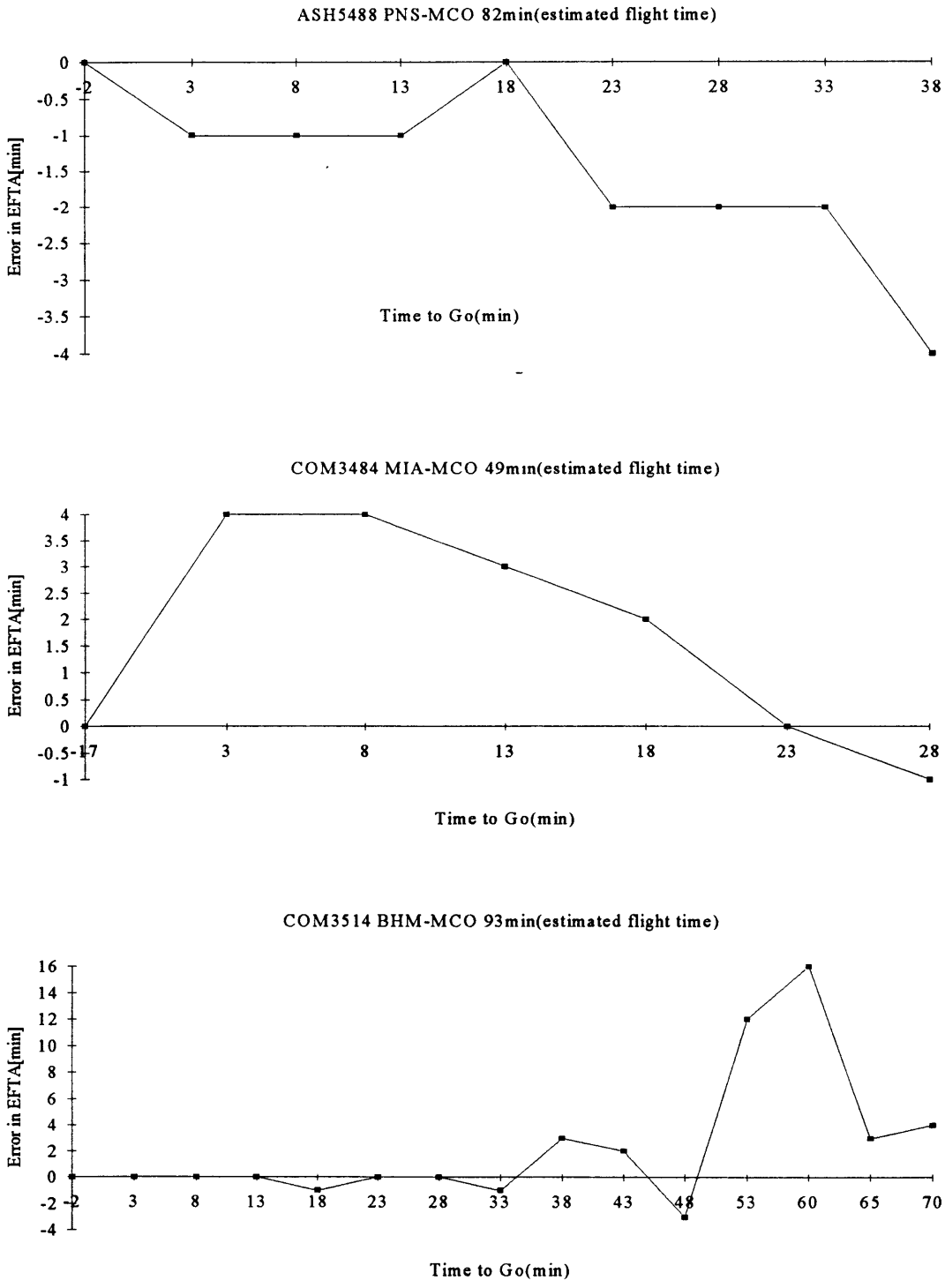
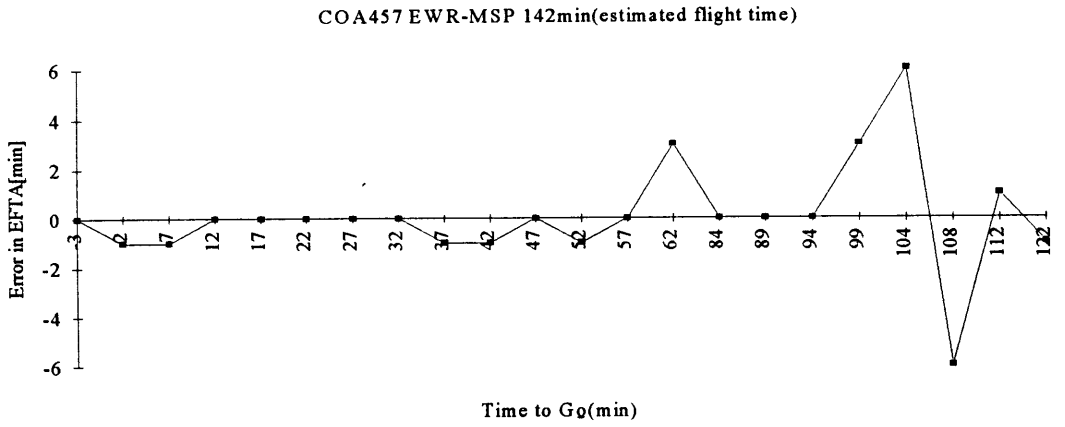
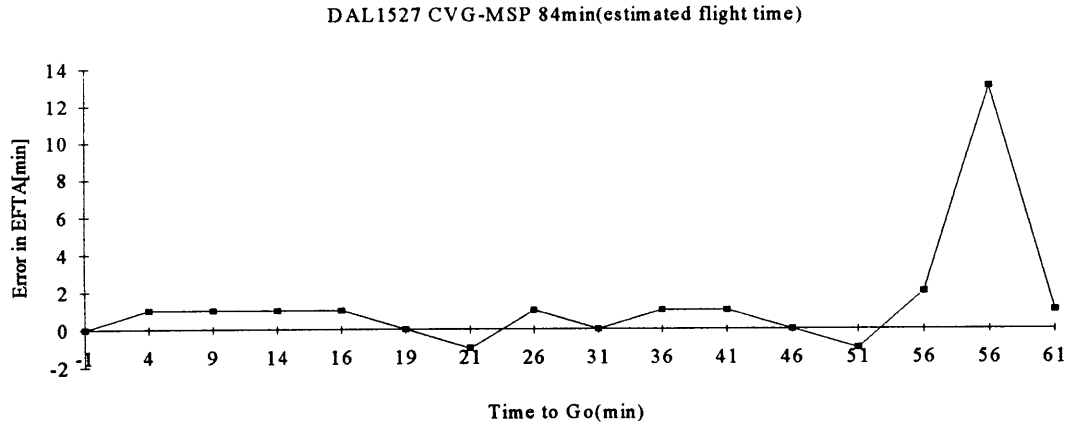


Fig3.2.2c Sample Histories of Estimation Errors(Prop)





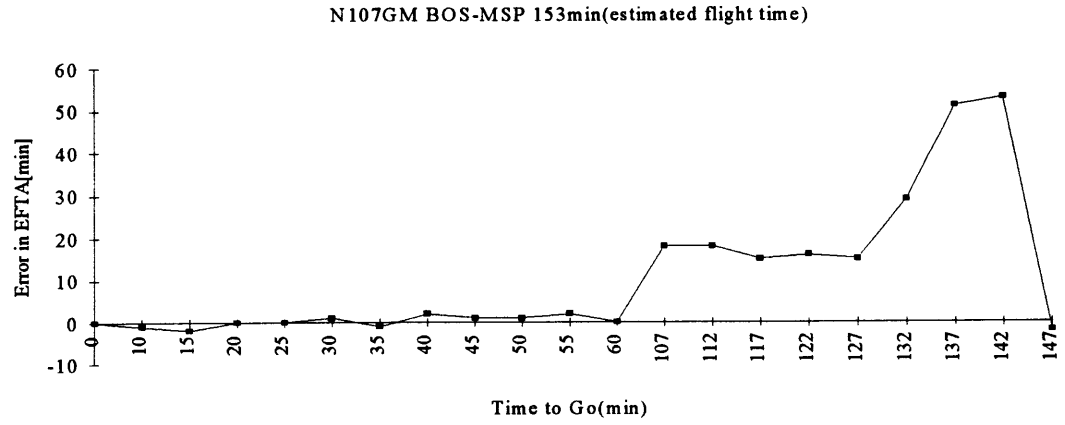


Fig3.2.3a Sample Histories of Estimation Errors(Jet)

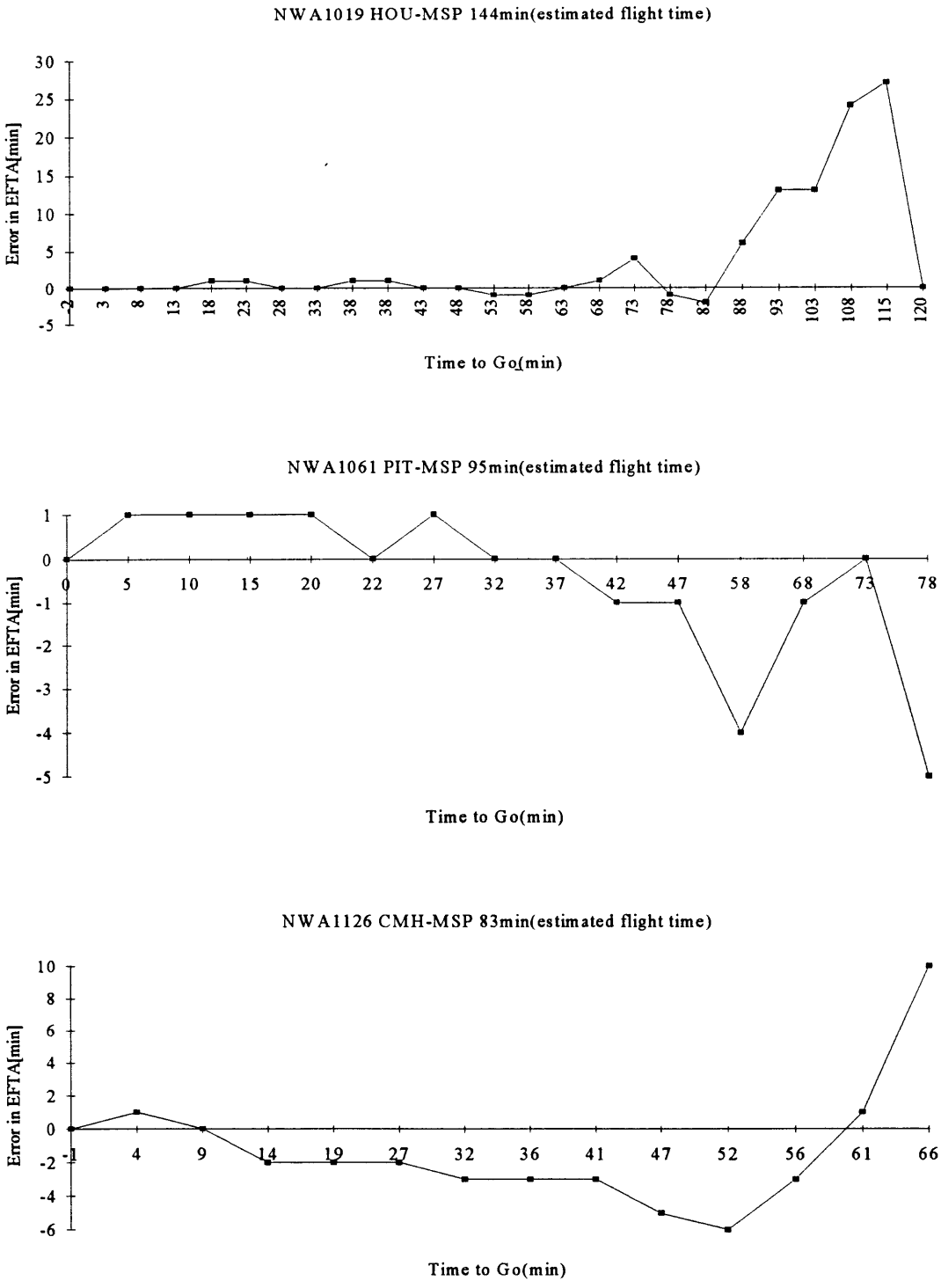


Fig3.2.3b Sample Histories of Estimation Errors(Jet)

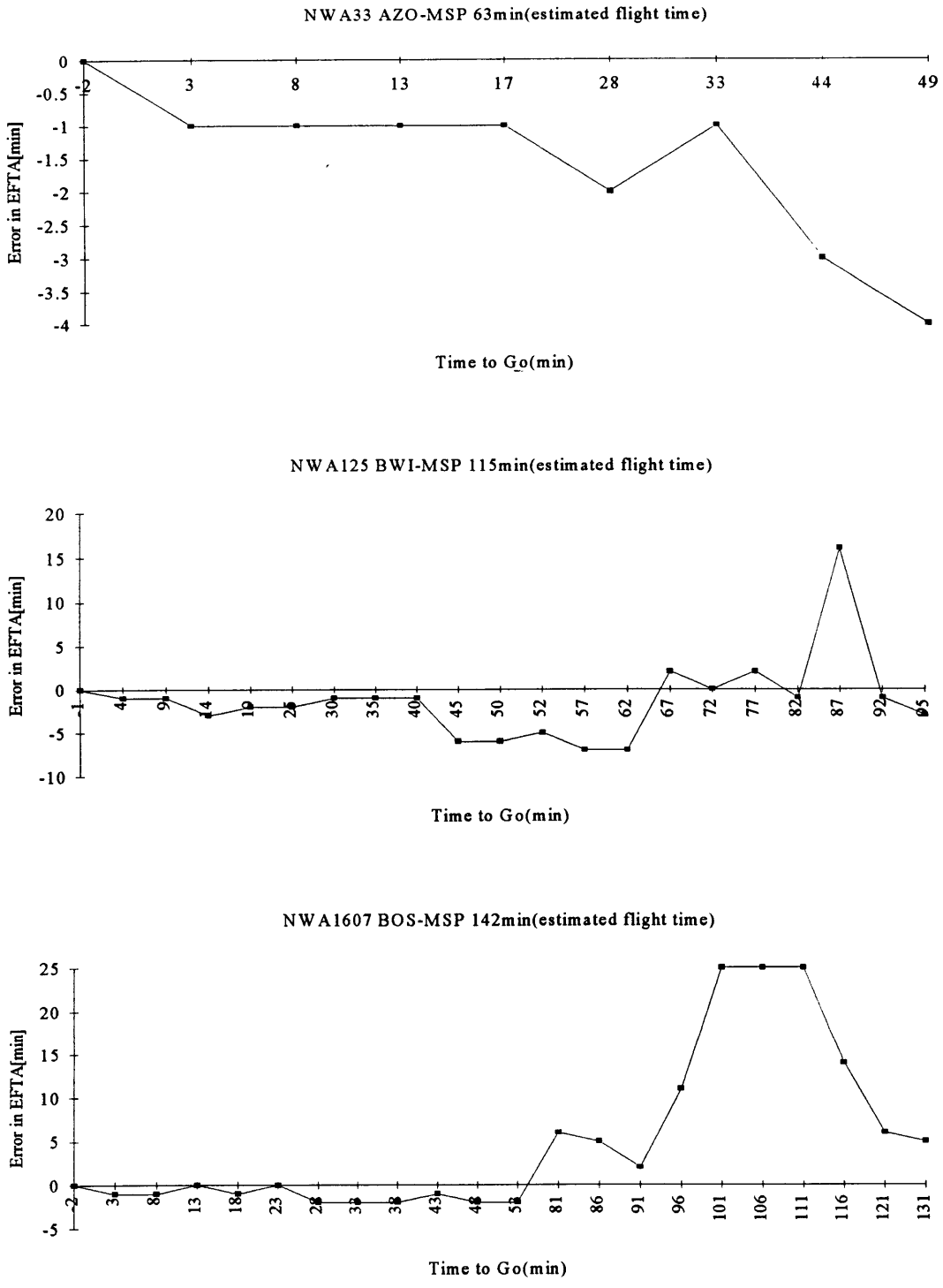
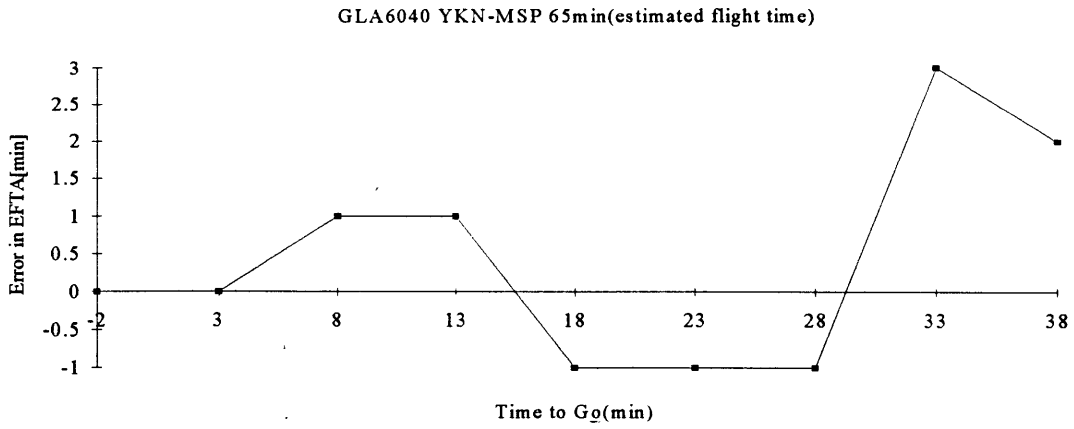
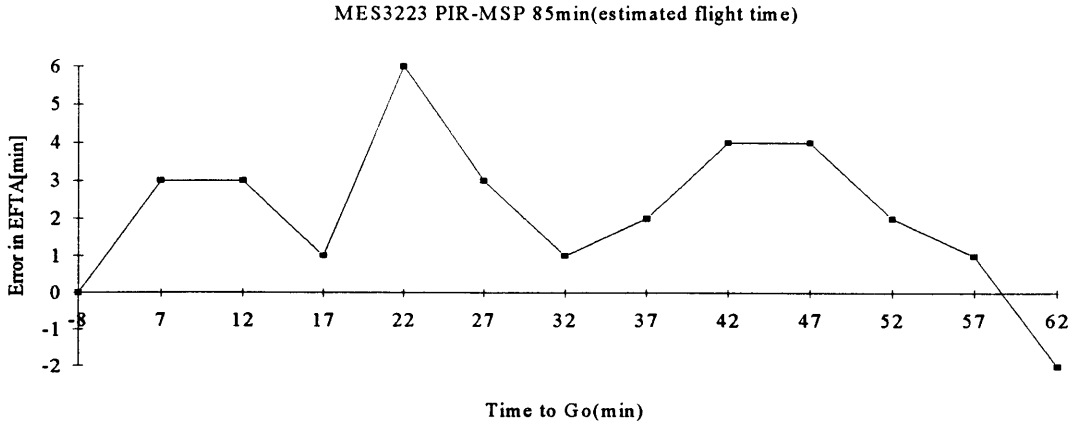


Fig3.2.3c Sample Histories of Estimation Errors(Jet)





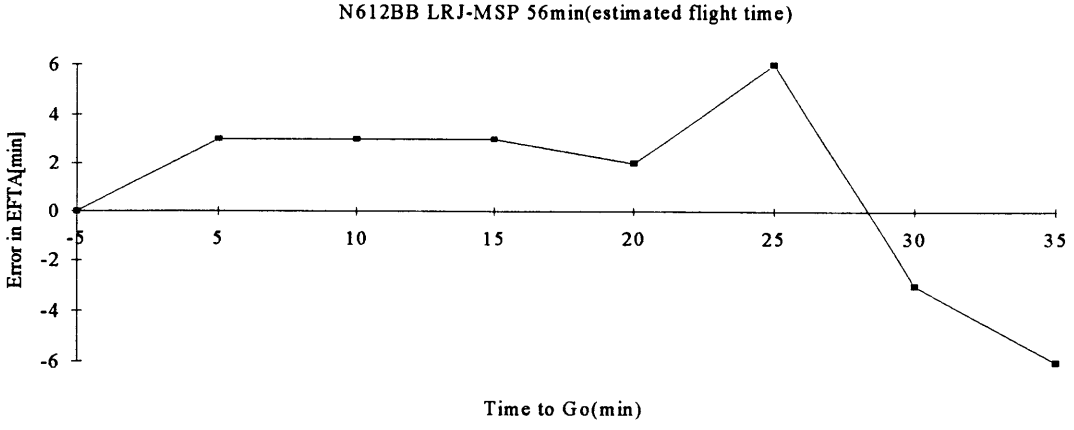


Fig3.2.3d Sample Histories of Estimation Errors(Prop)

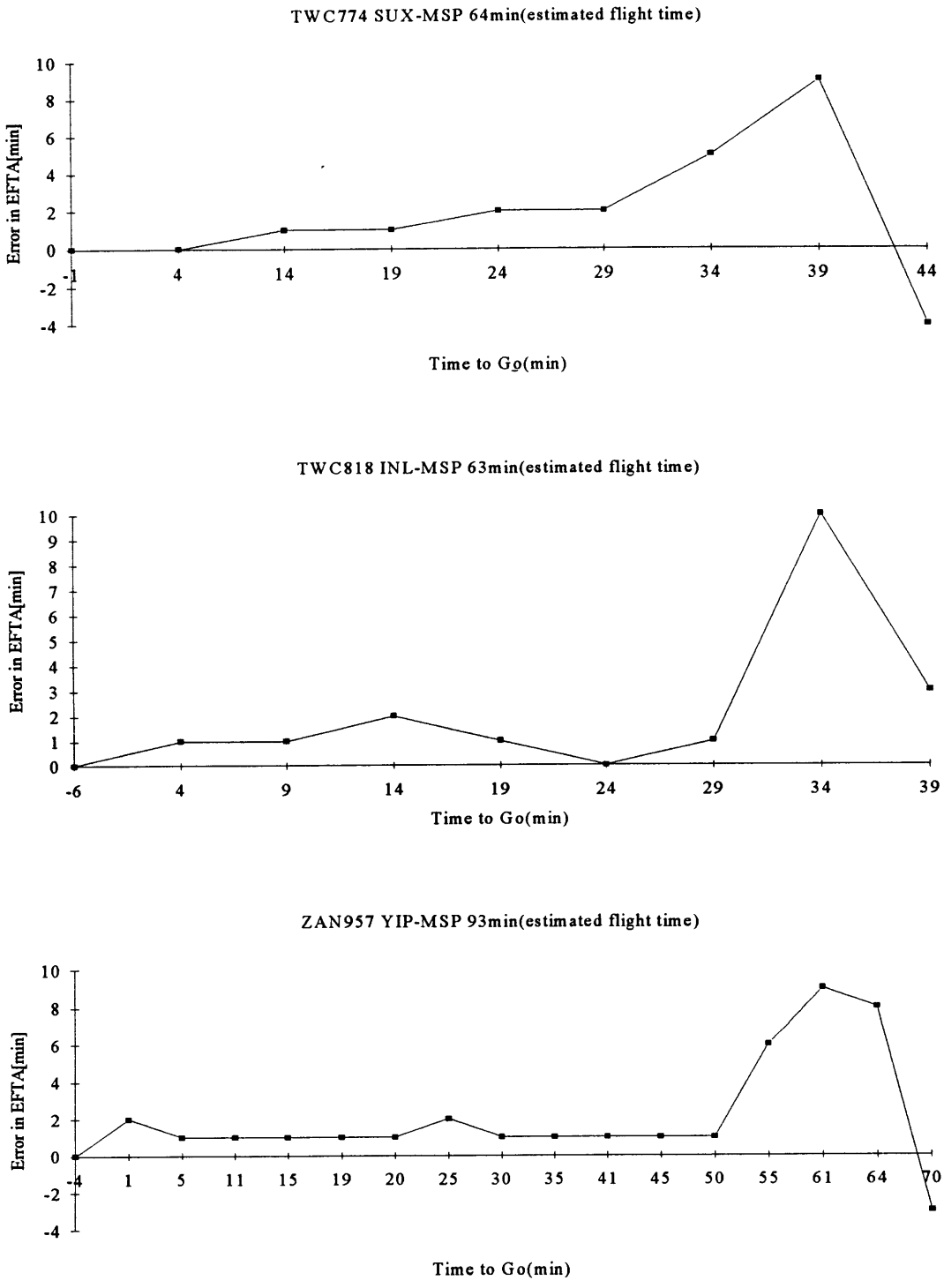


Fig3.2.3e Sample Histories of Estimation Errors(Prop)

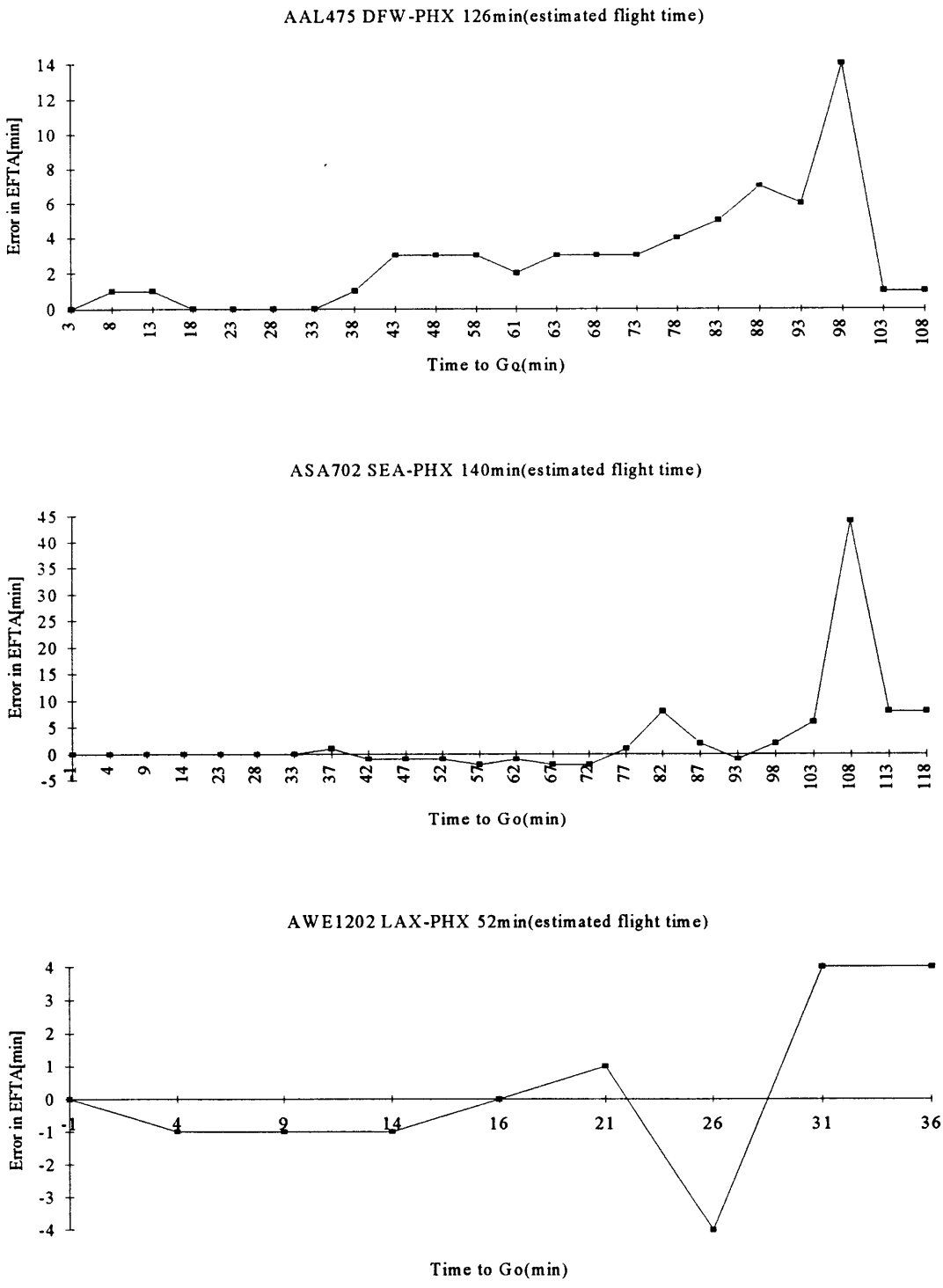
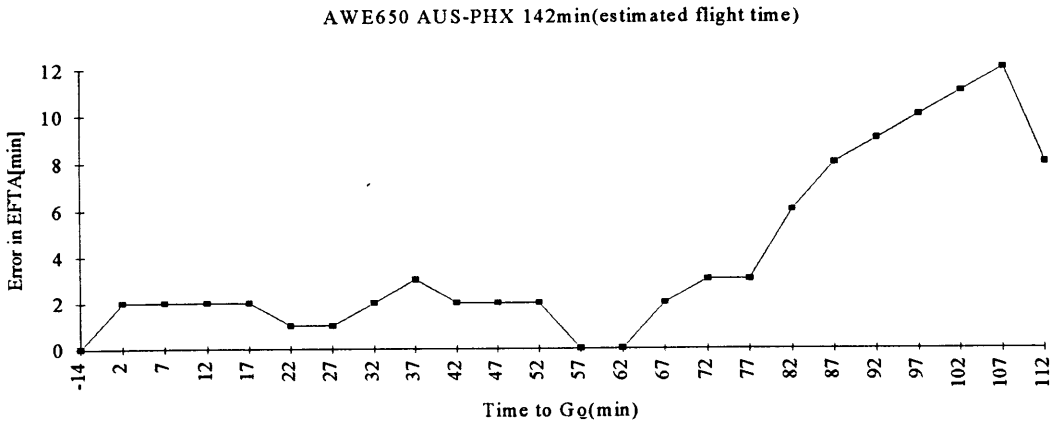
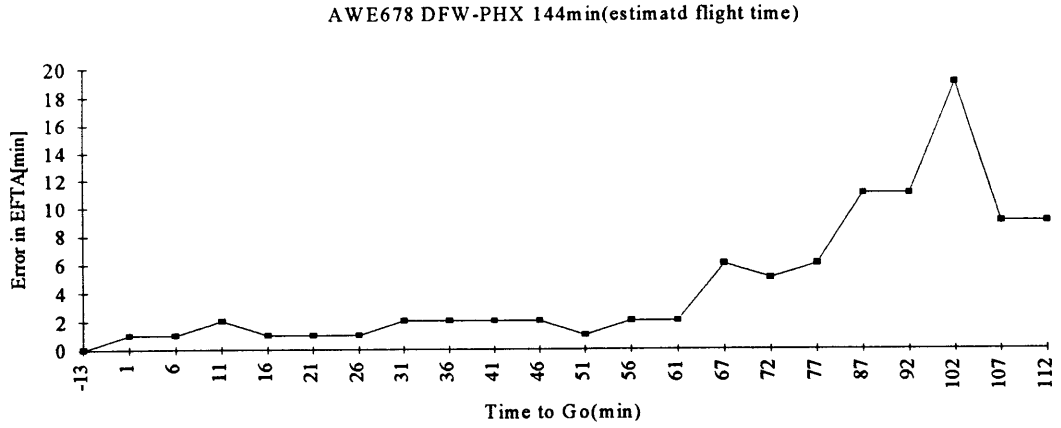


Fig3.2.4a Sample Histories of Estimation Errors(Jet)





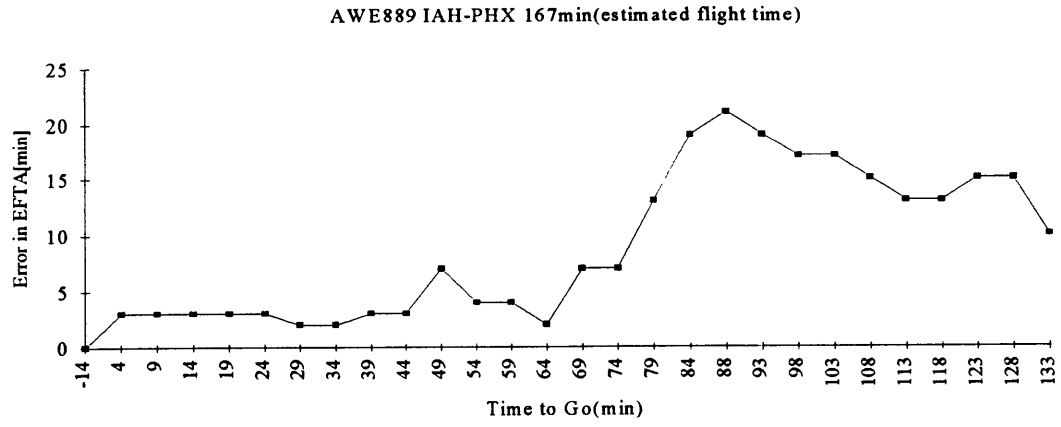
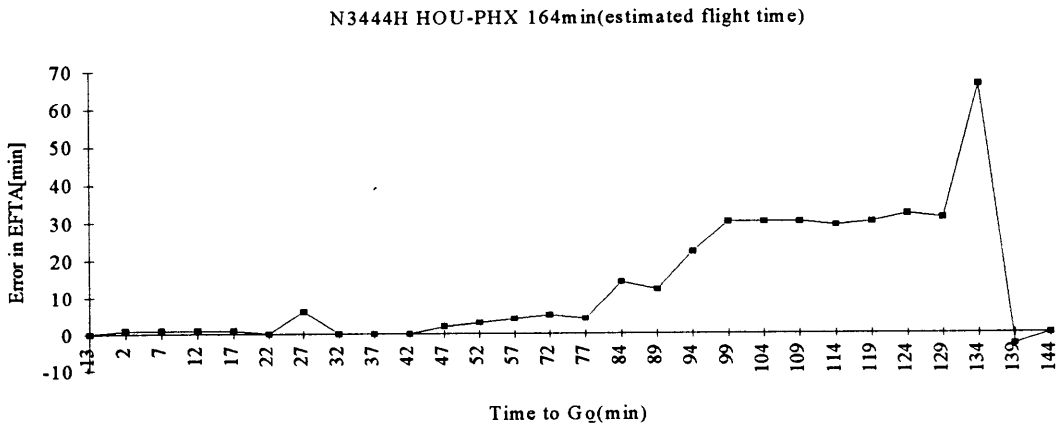
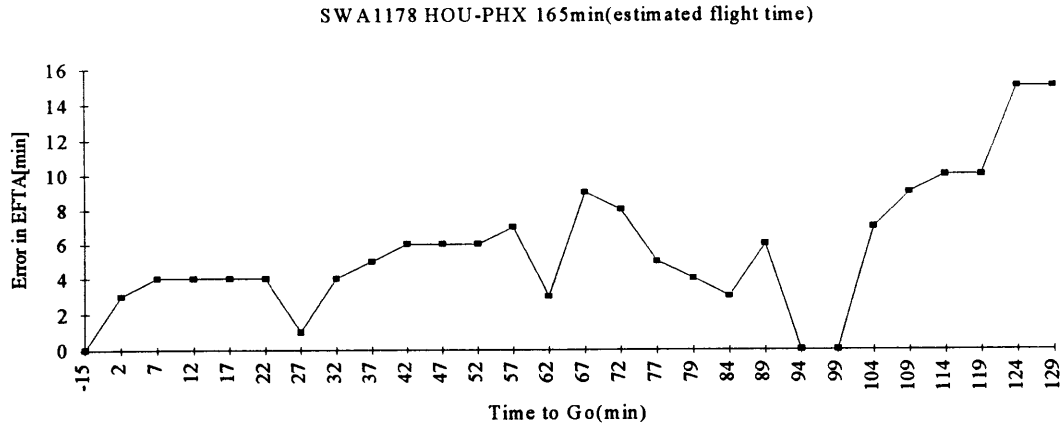


Fig3.2.4b Sample Histories of Estimation Errors(Jet)





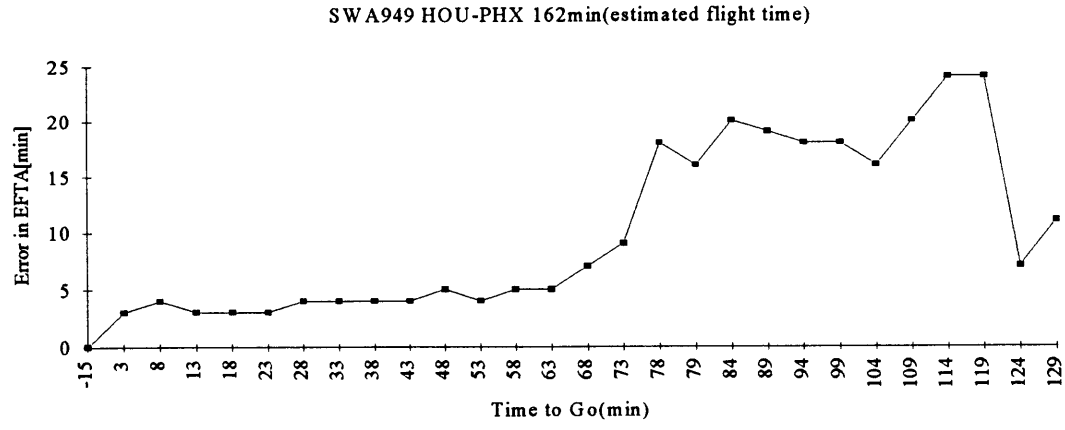
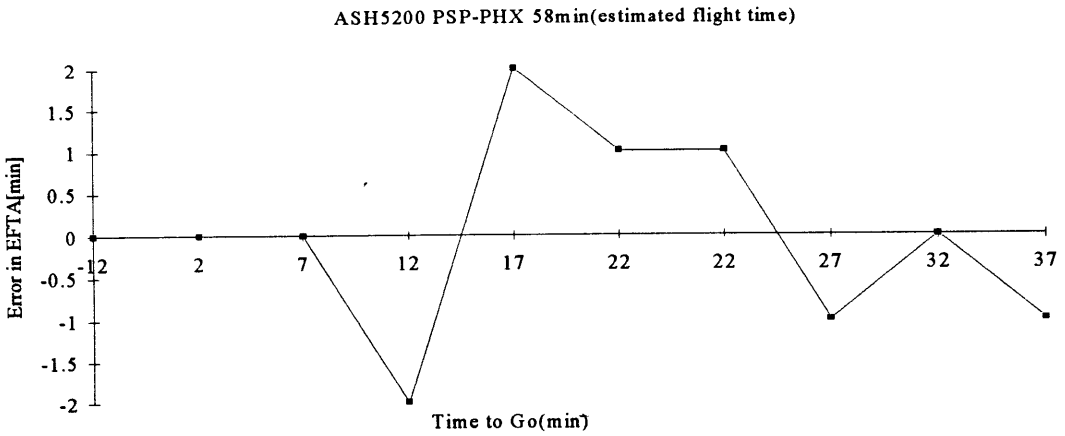
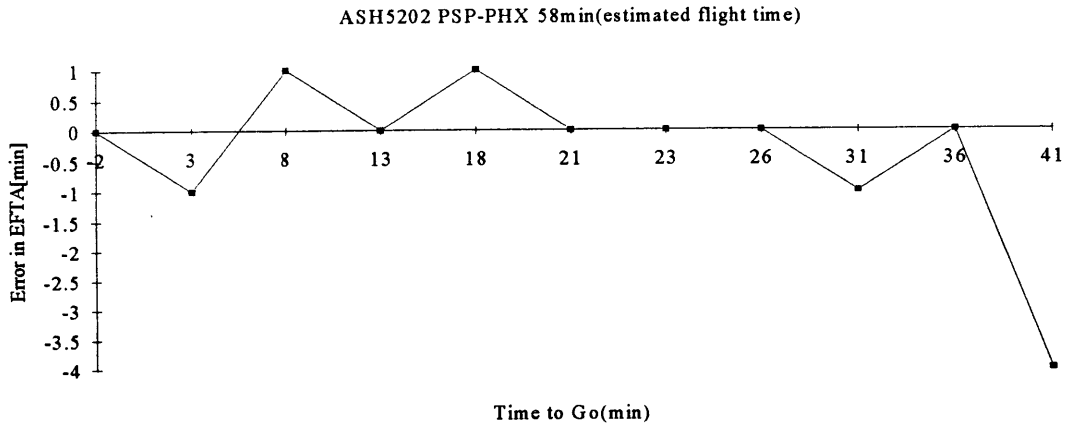


Fig3.2.4c Sample Histories of Estimation Errors(Jet)





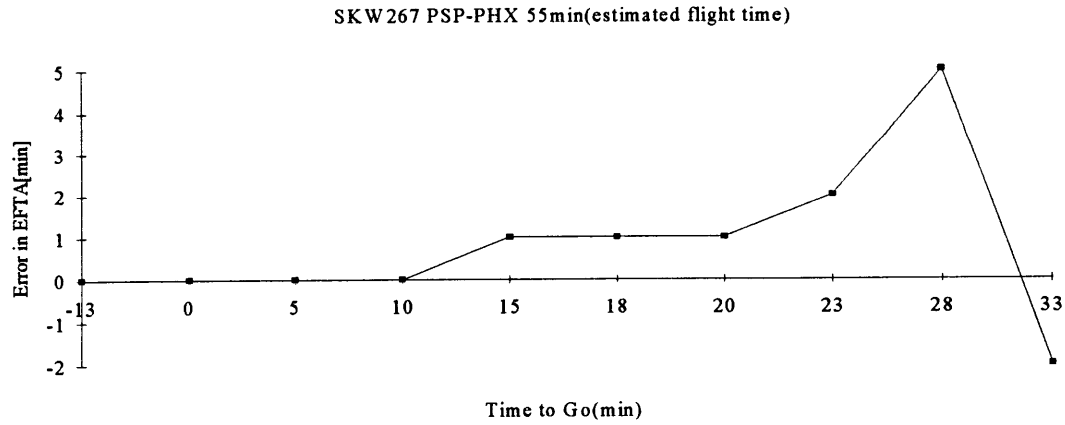


Fig3.2.4d Sample Histories of Estimation Errors(Prop)

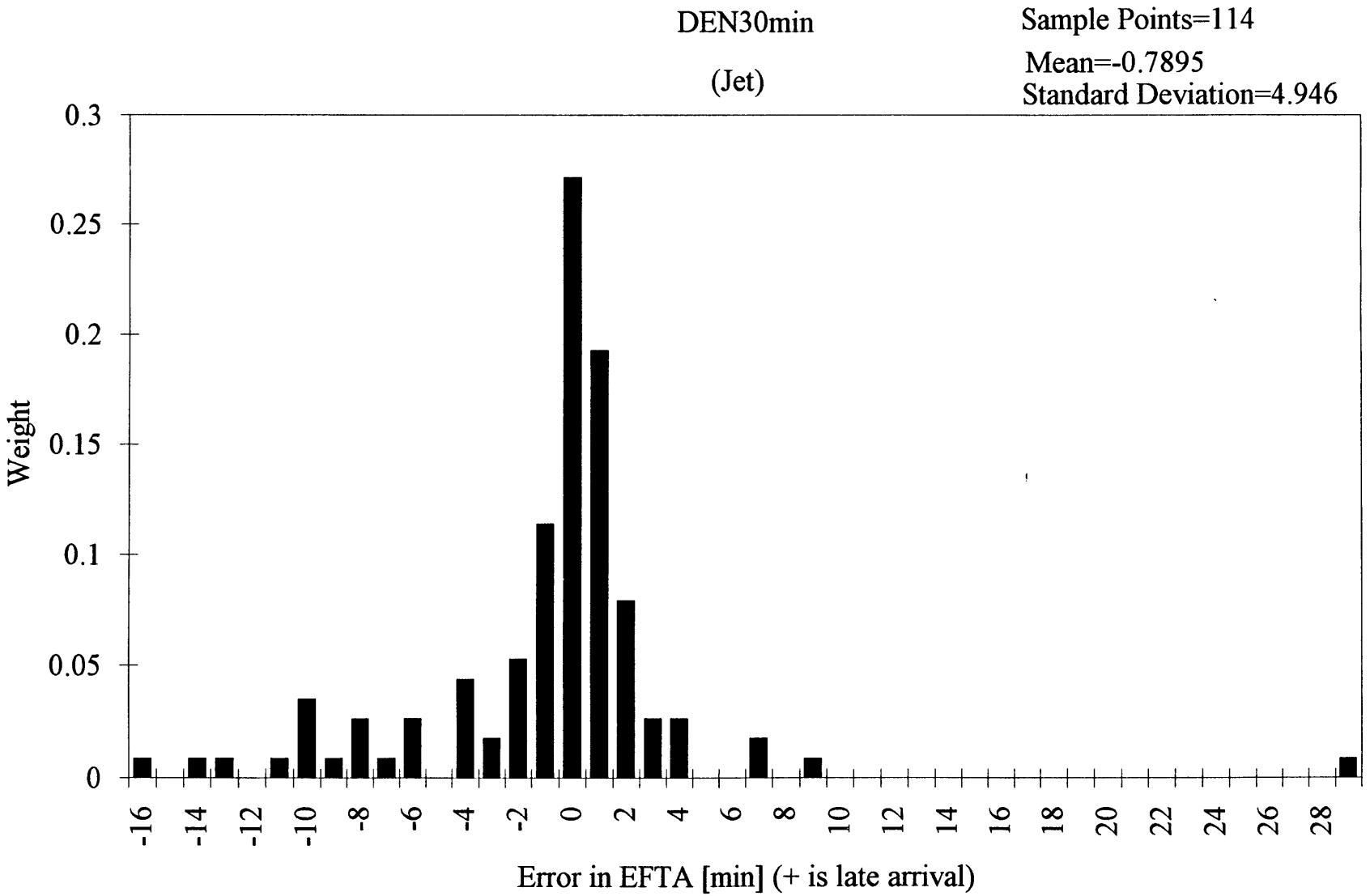


Fig.3.3.1a Distribution of Errors in EFTA at30 min-DEN Flights

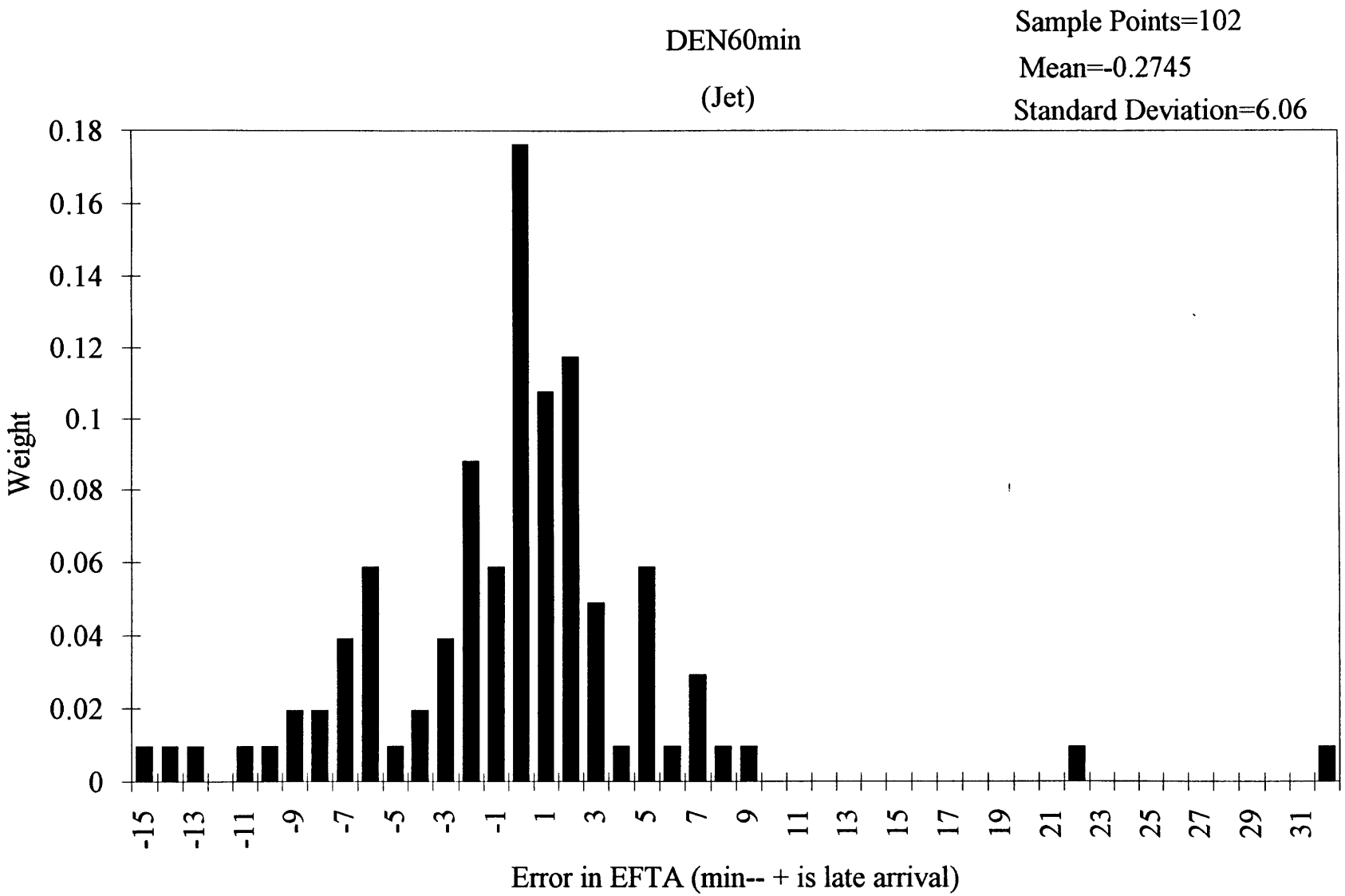


Fig.3.3.1b Distribution of Errors in EFTA at 60min-DEN Flights

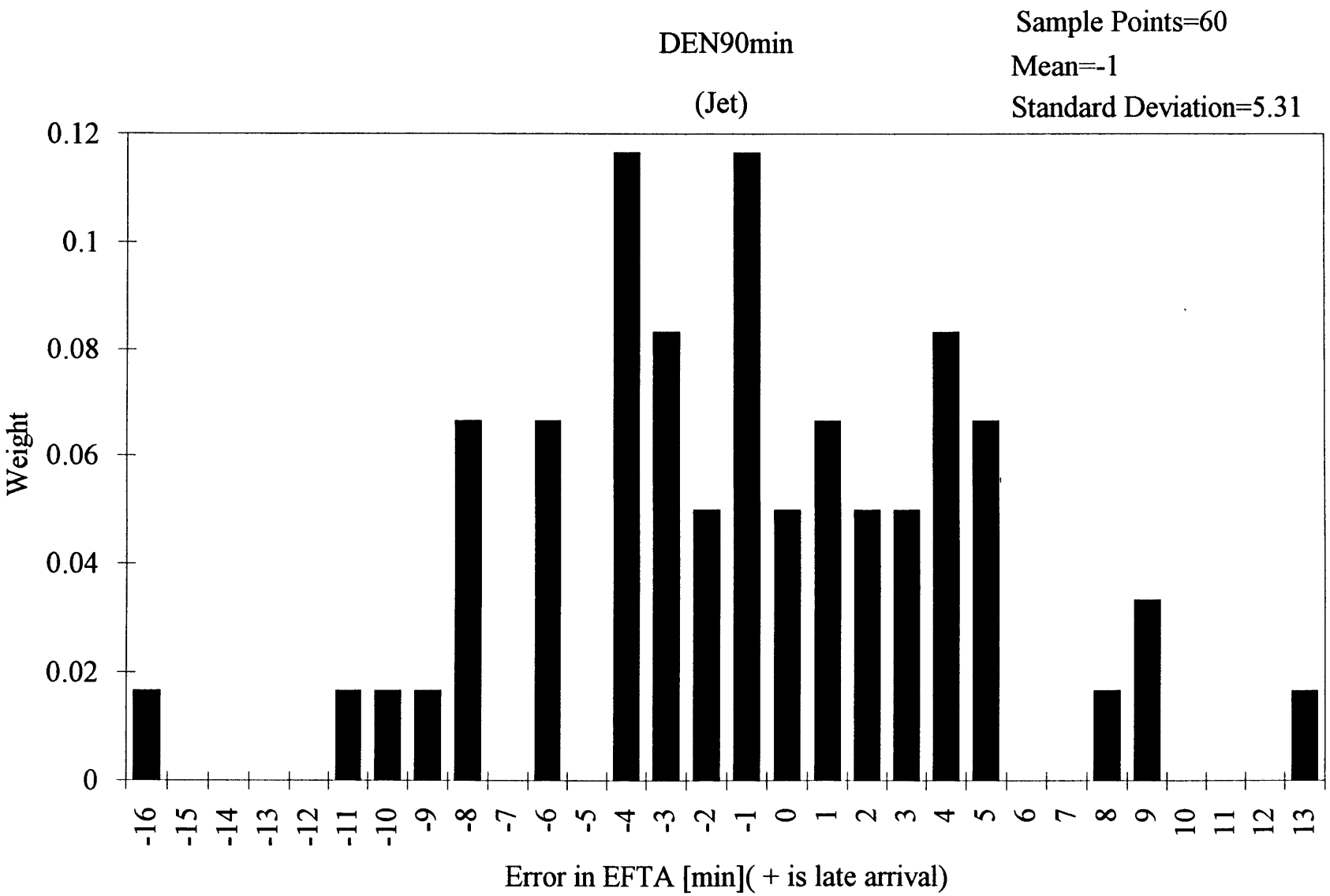


Fig.3.3.1c Distribution of Errors in EFTA at 90min-DEN Flights

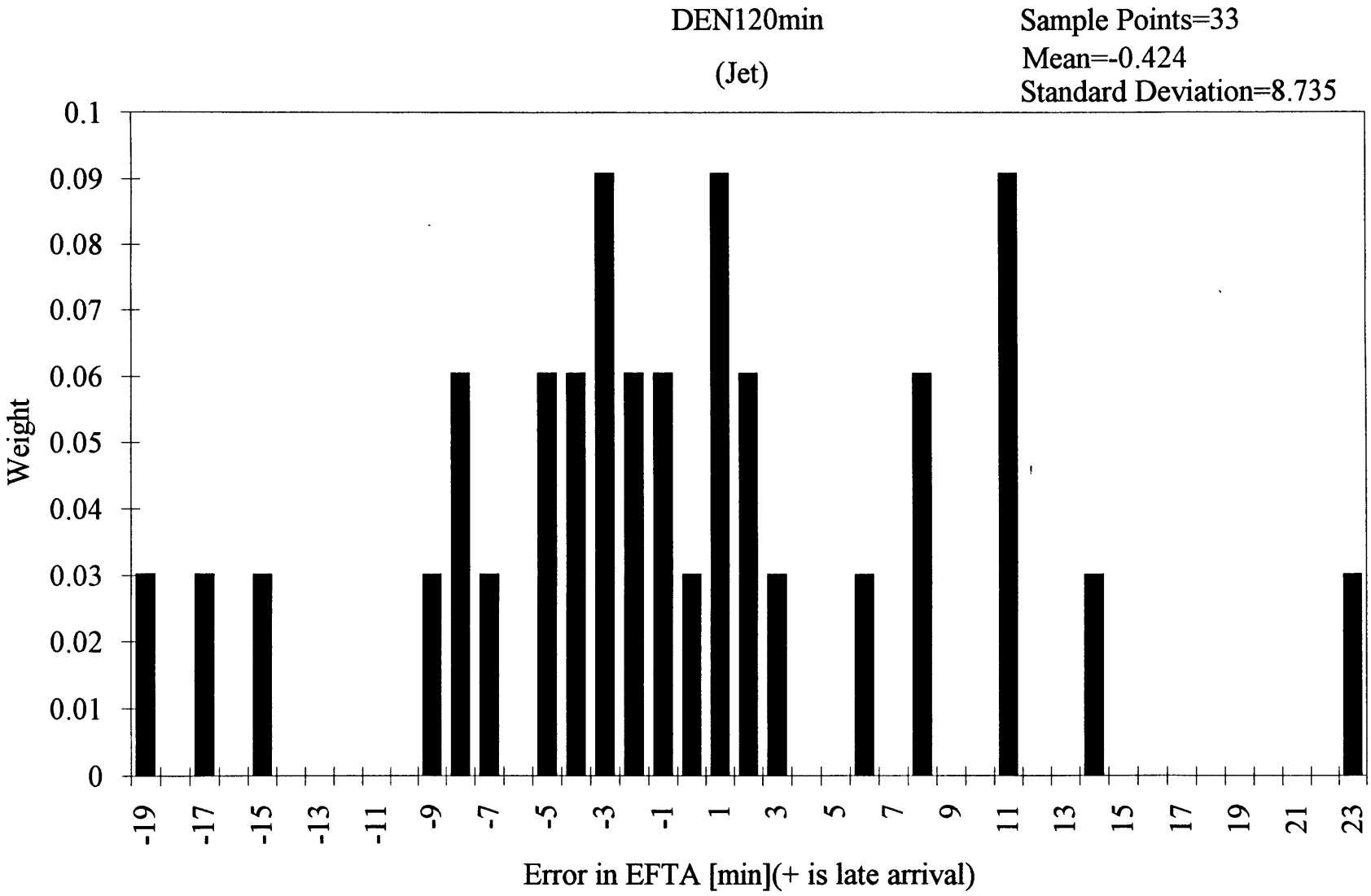


Fig.3.3.1d Distribution of Errors in EFTA at 120min-DEN Flights

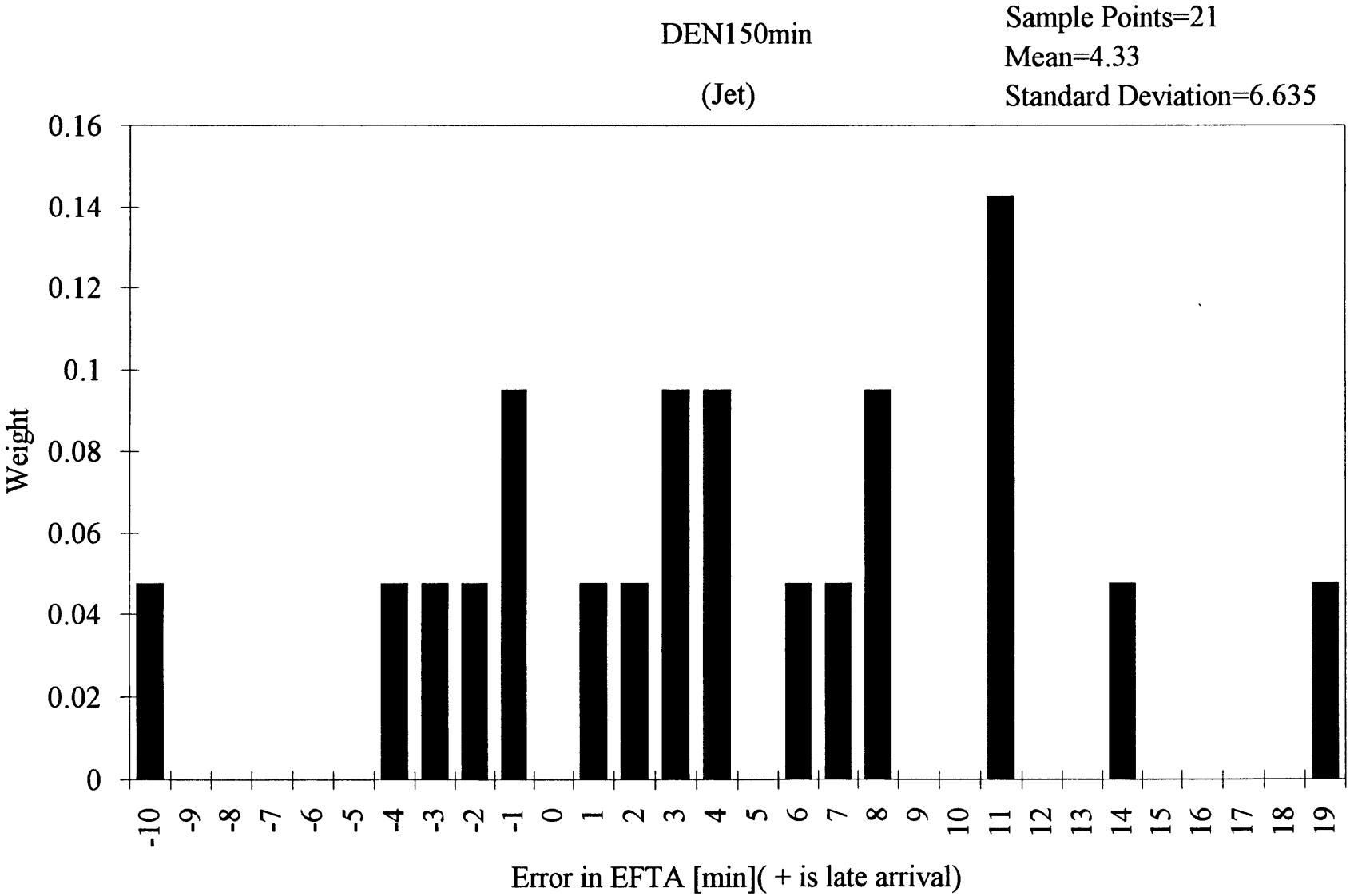


Fig.3.3.1e Distribution of Errors in EFTA at 120min-DEN Flights

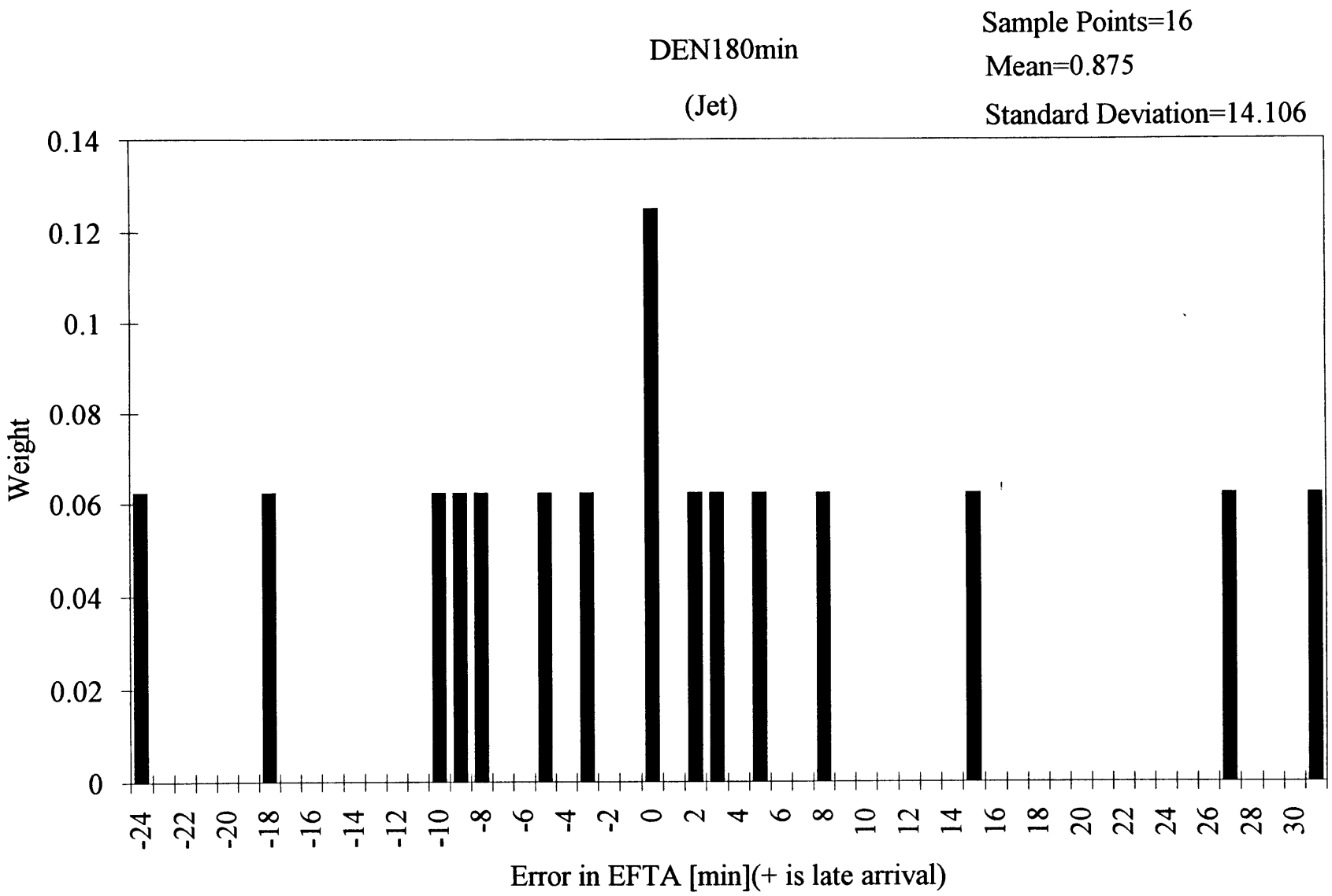


Fig.3.3.1f Distribution of Errors in EFTA at 180min-DEN Flights

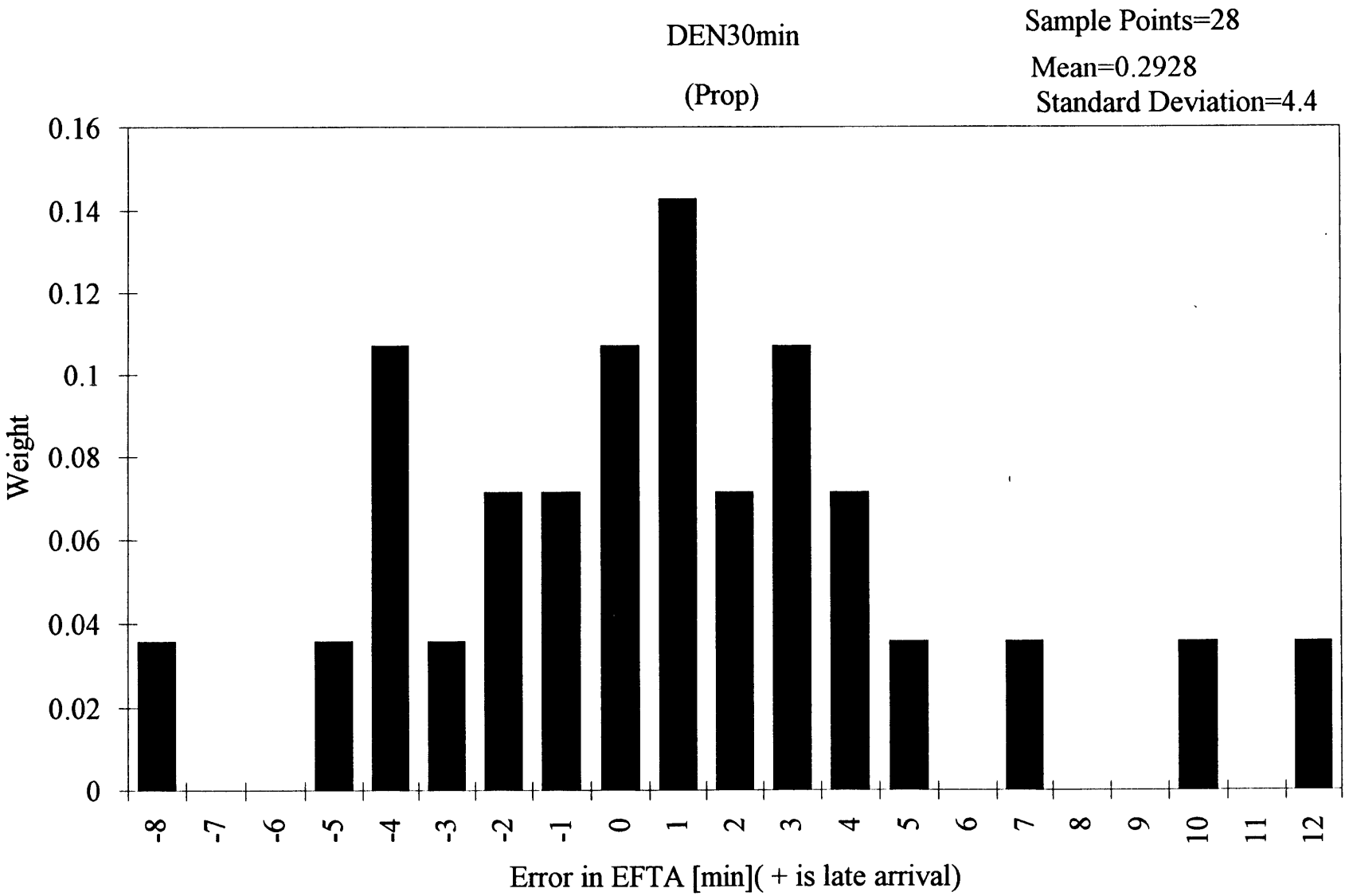


Fig. 3.3.1g Distribution of Errors in EFTA at 30min-DEN Flights

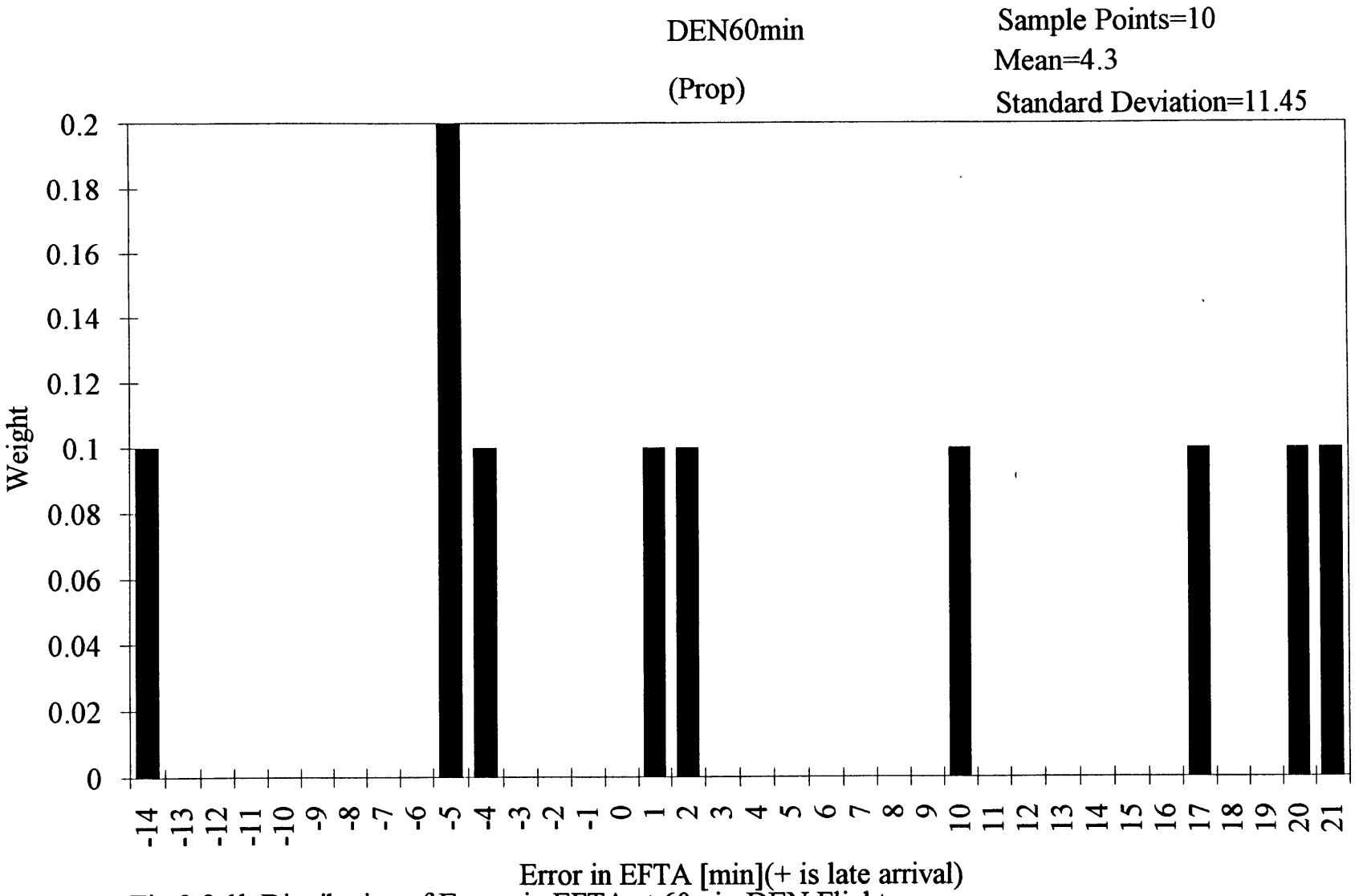


Fig.3.3.1h Distribution of Errors in EFTA at 60min-DEN Flights

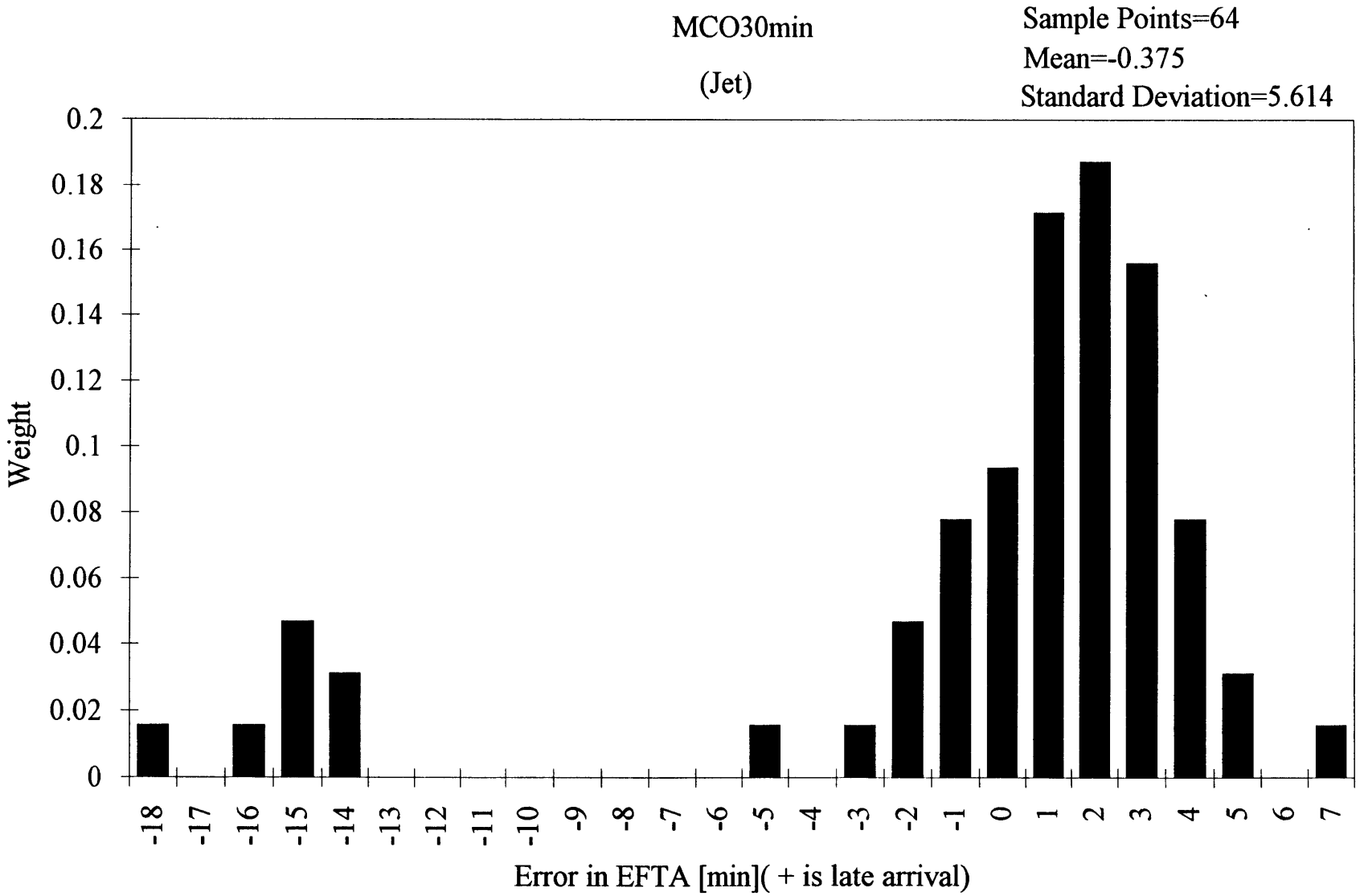


Fig.3.3.2a Distribution of Errors in EFTA at 30min-MCO Flights

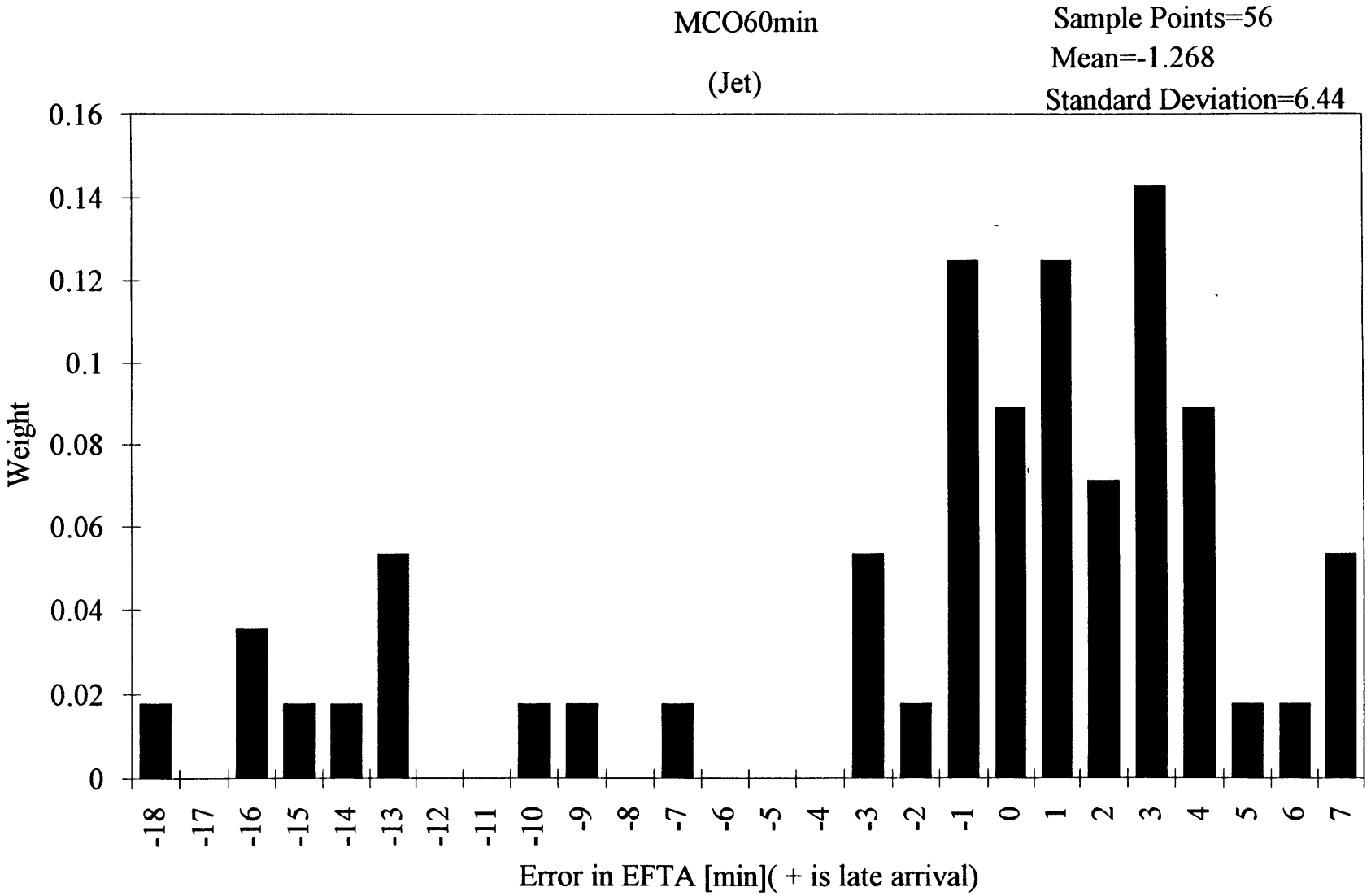


Fig.3.3.2b Distribution of Errors in EFTA at 60min-MCO Flights

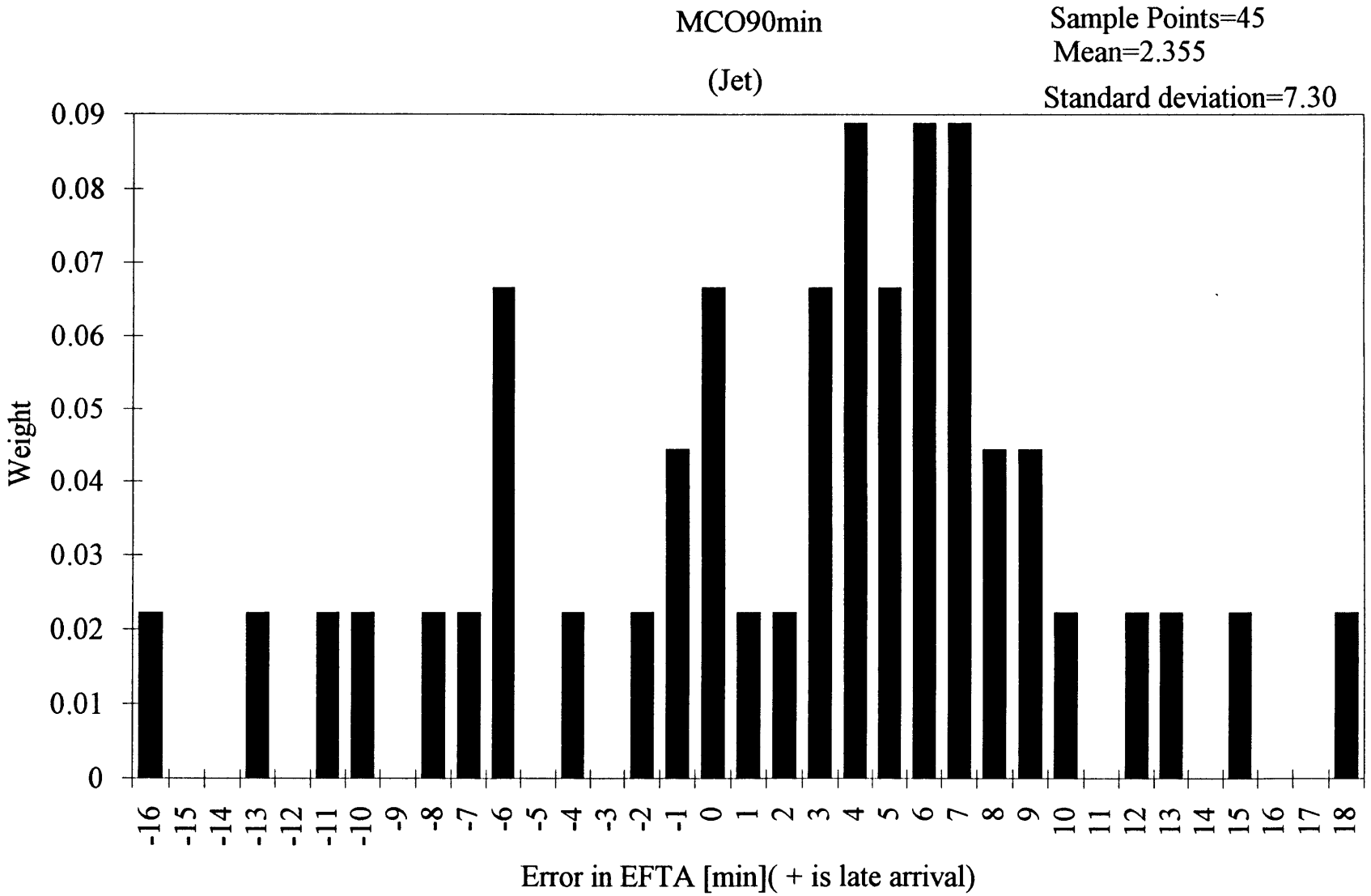


Fig.3.3.2c Distribution of Errors in EFTA at 90min-MCO Flights

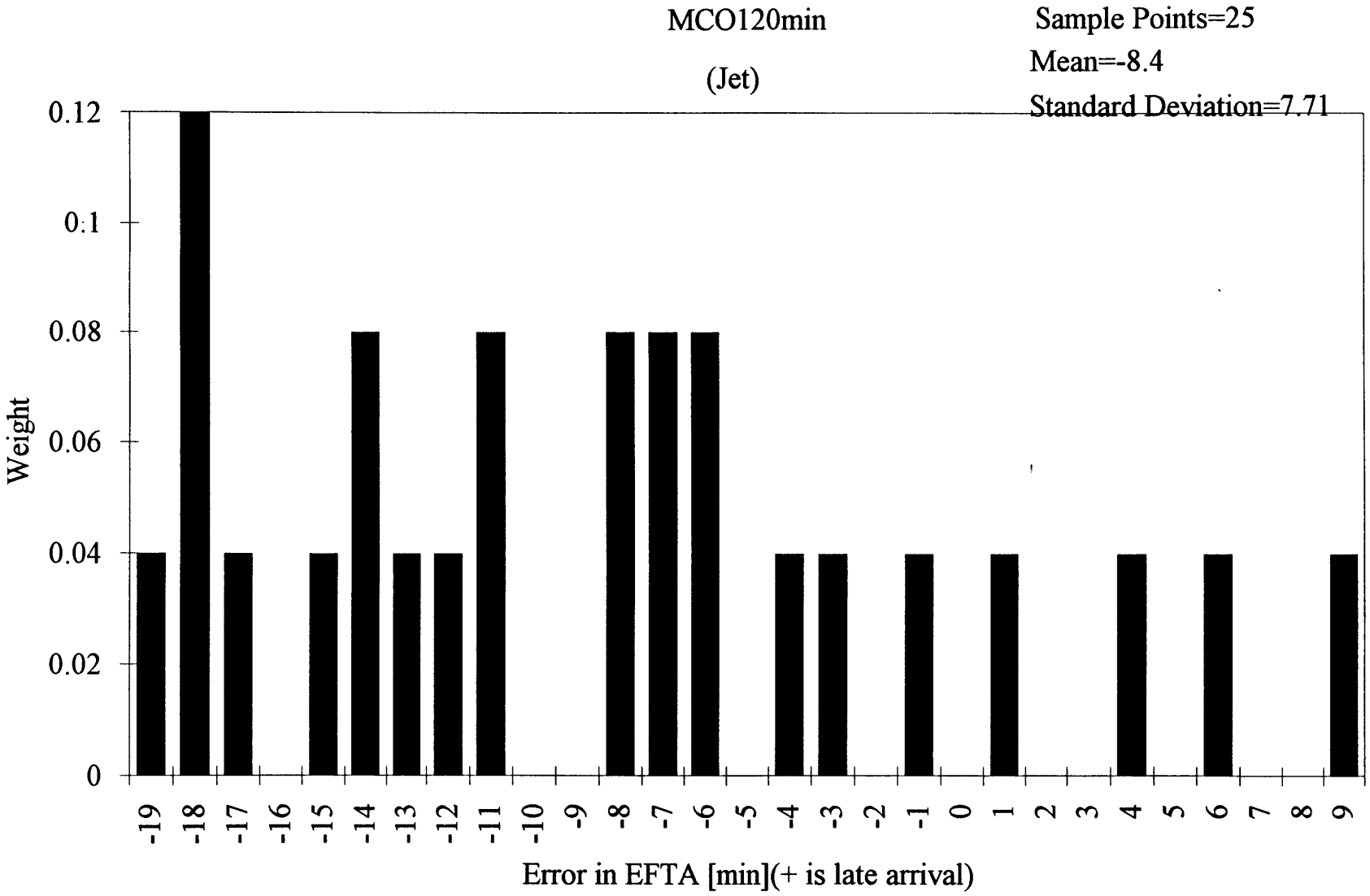


Fig.3.3.2d Distribution of Errors in EFTA at 120min-MCO

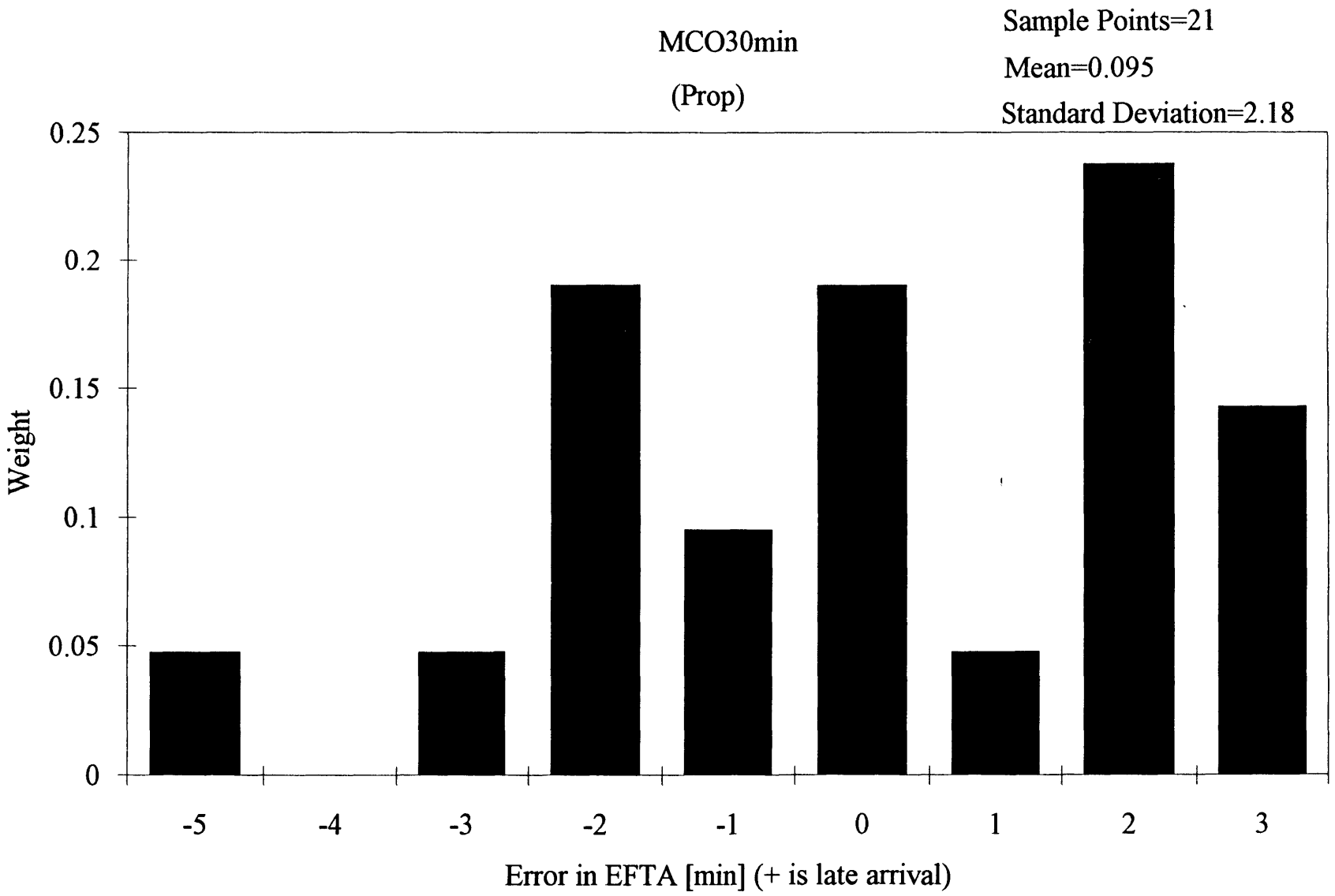


Fig.3.3.2e Distribution of Errors in EFTA at 30min-MCO Flights

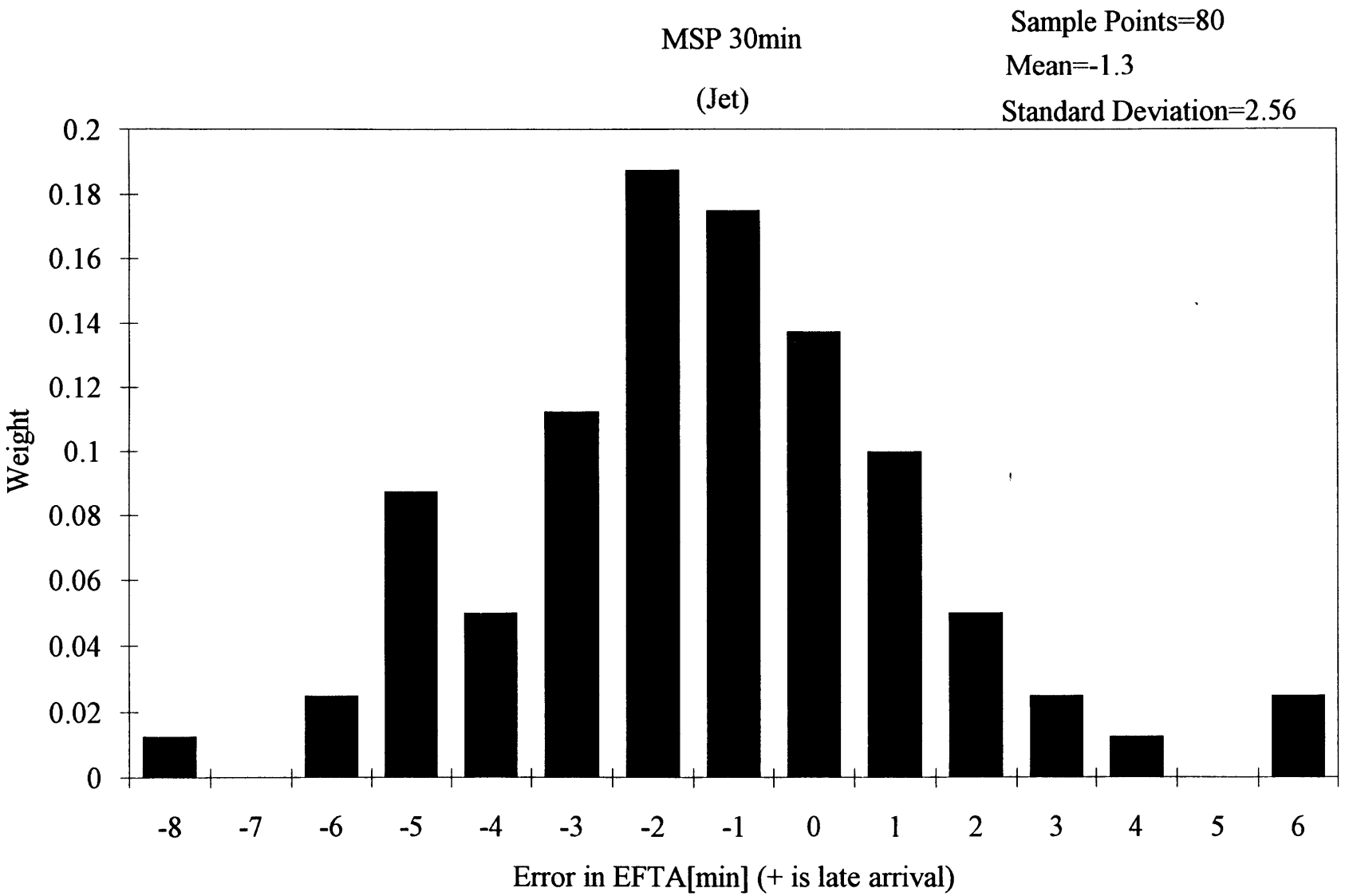


Fig.3.3.3a Distribution of Errors in EFTA at 30min-MSP Flights

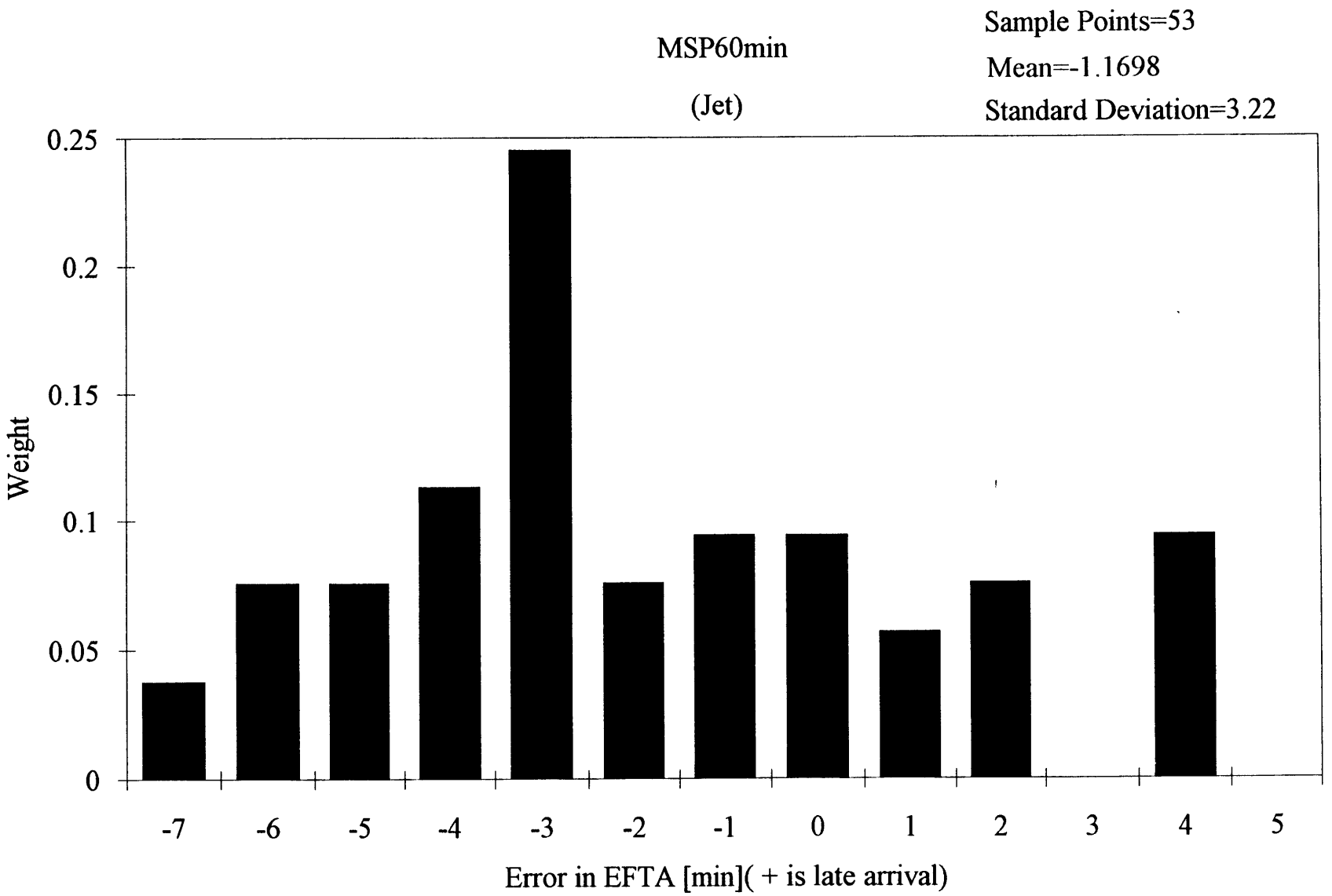


Fig.3.3.3b Distribution of Errors in EFTA at 60min-MSP Flights

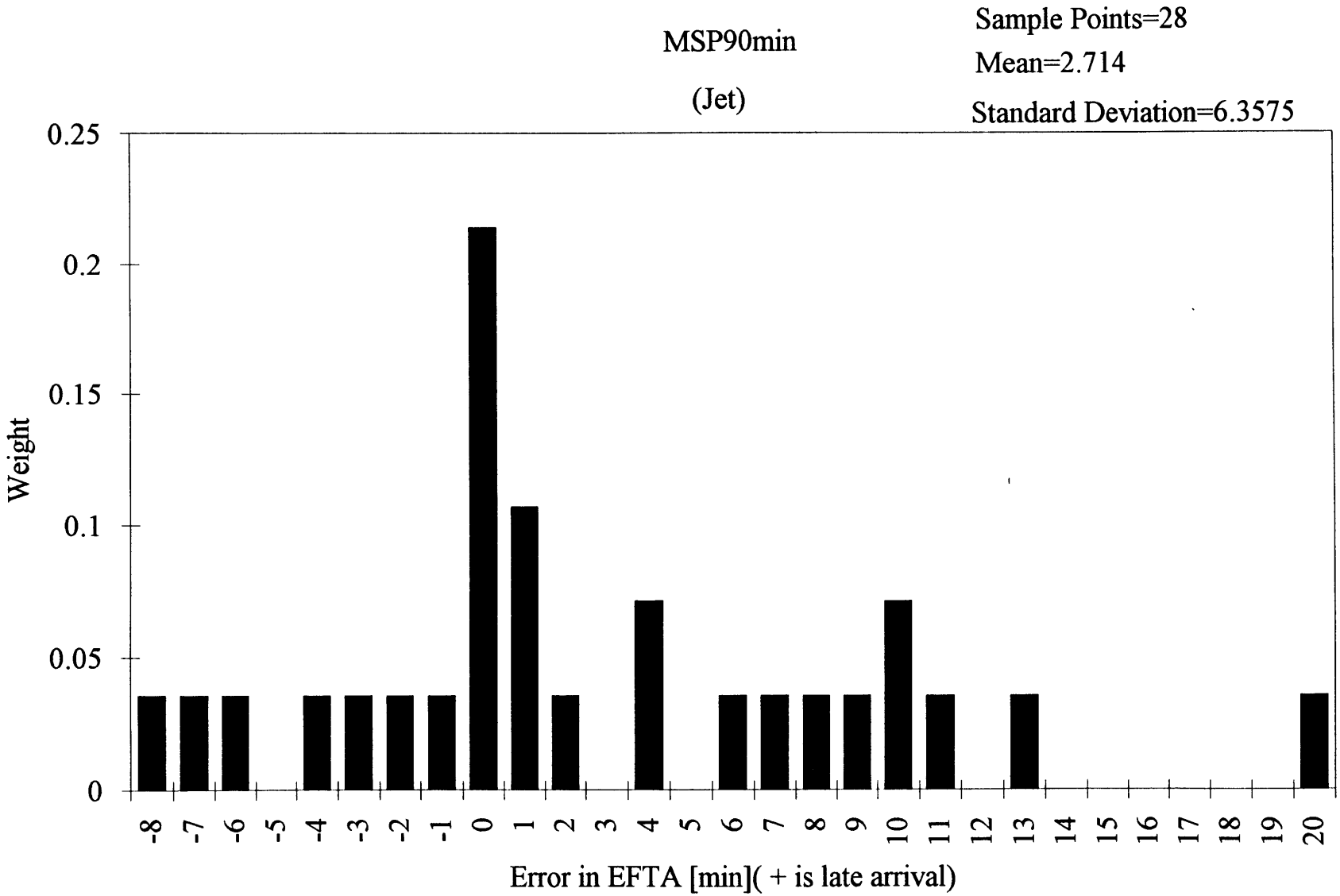


Fig.3.3.3c Distribution of Errors in EFTA at 90min-MSP Flights

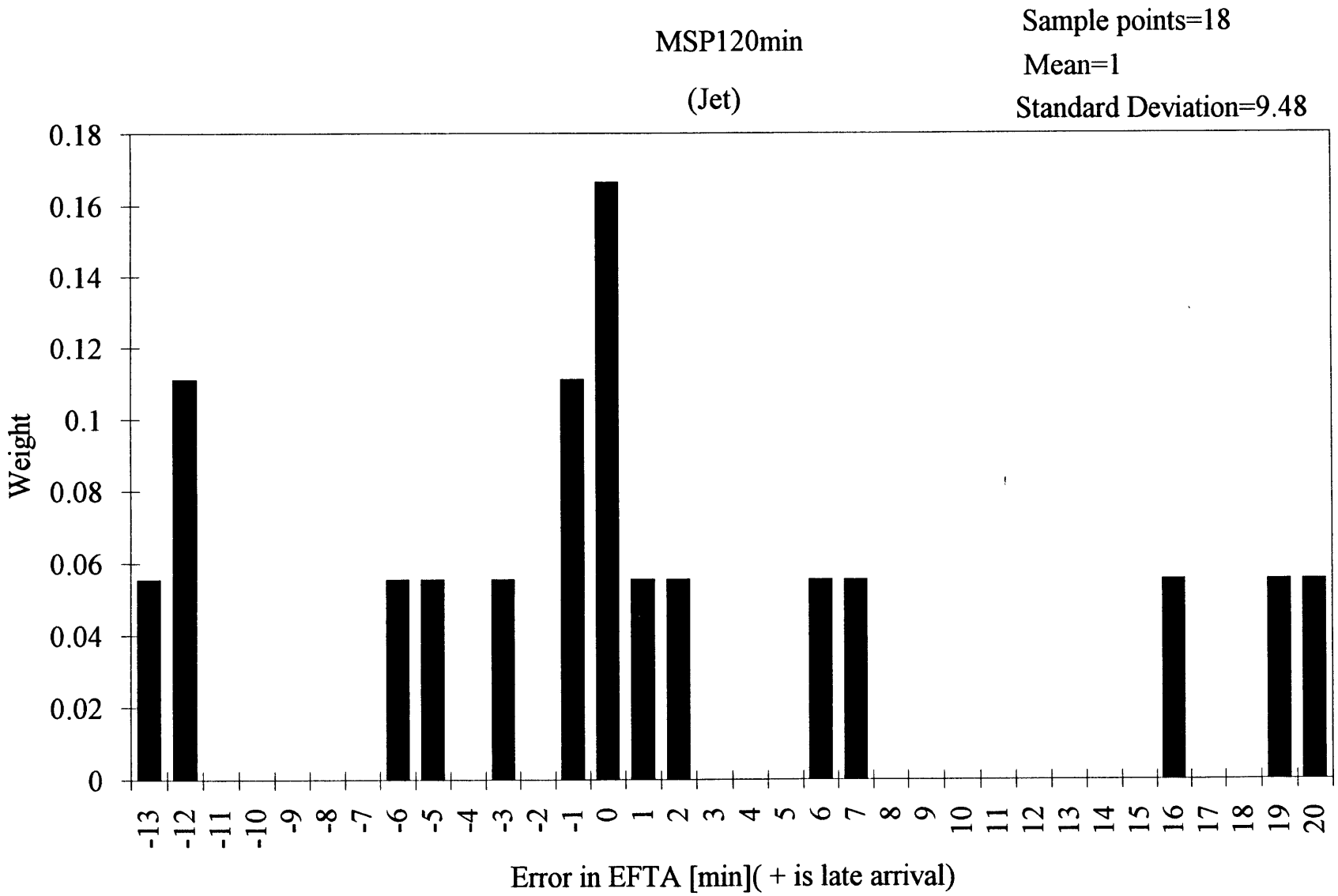


Fig.3.3.3d Distribution of Errors in EFTA at 120min-MSP Flights

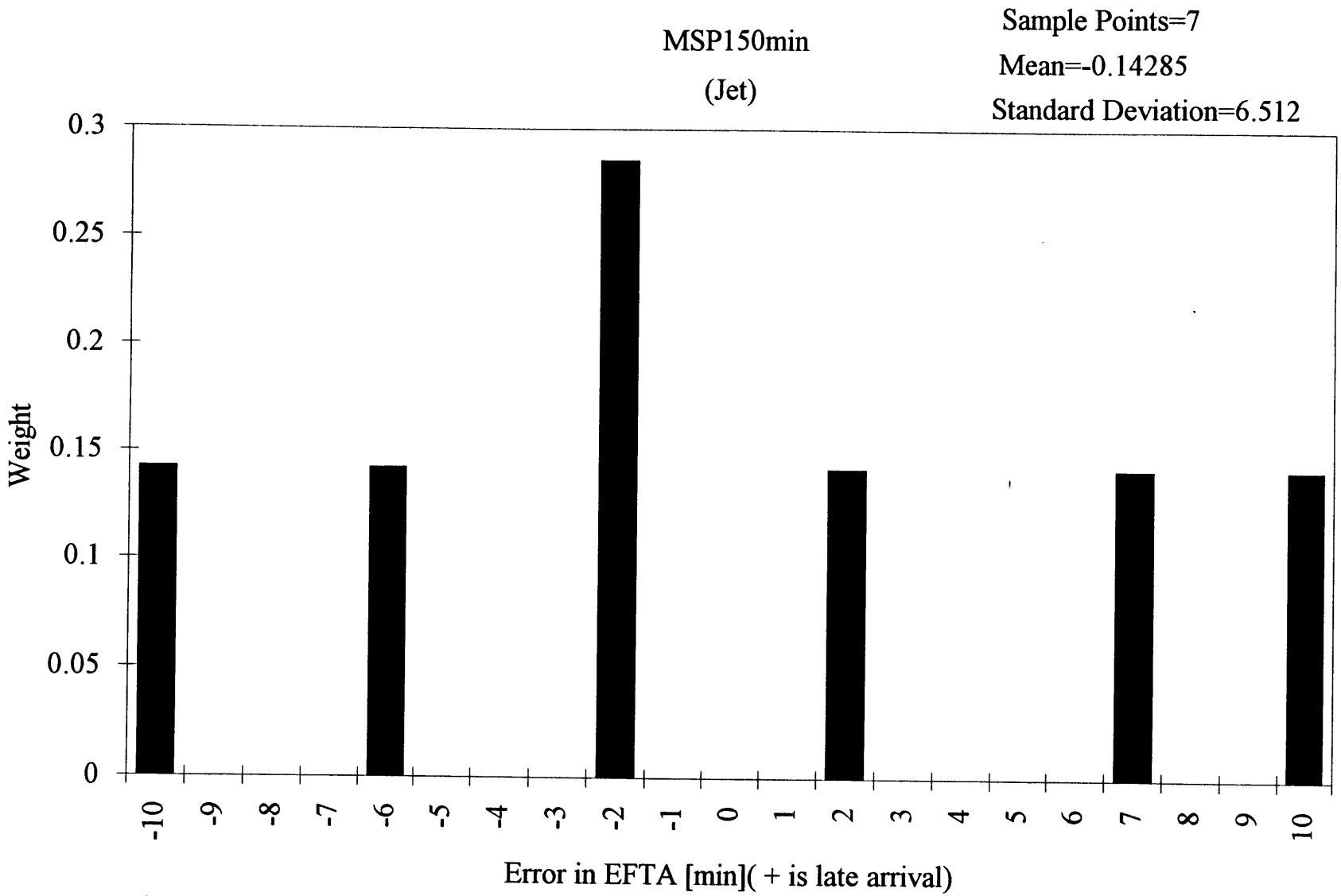


Fig.3.3.3e Distribution of Errors in EFTA at 150min-MSP Flights

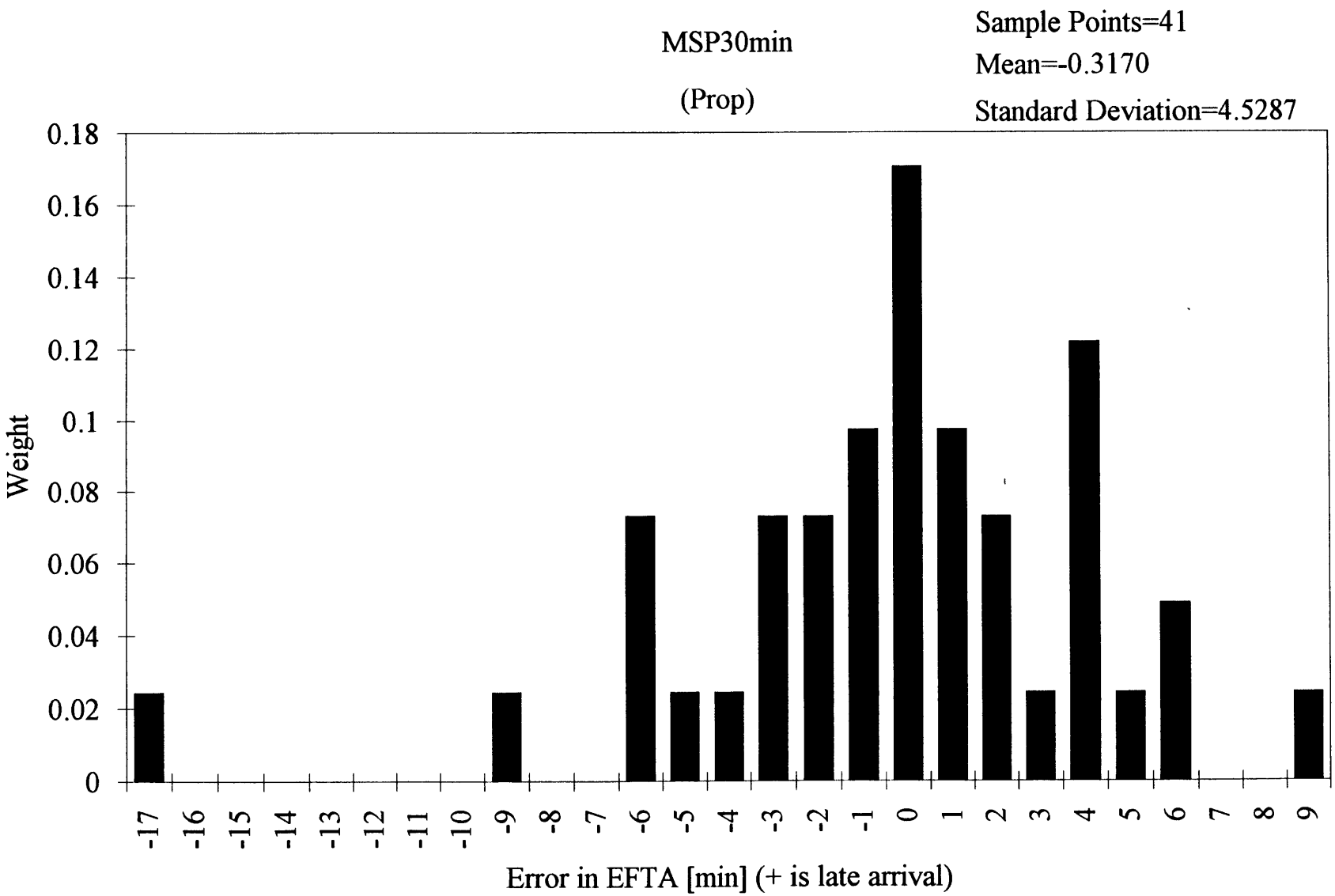


Fig.3.3.3.f Distribution of Errors in EFTA at 30min-MSP Flights

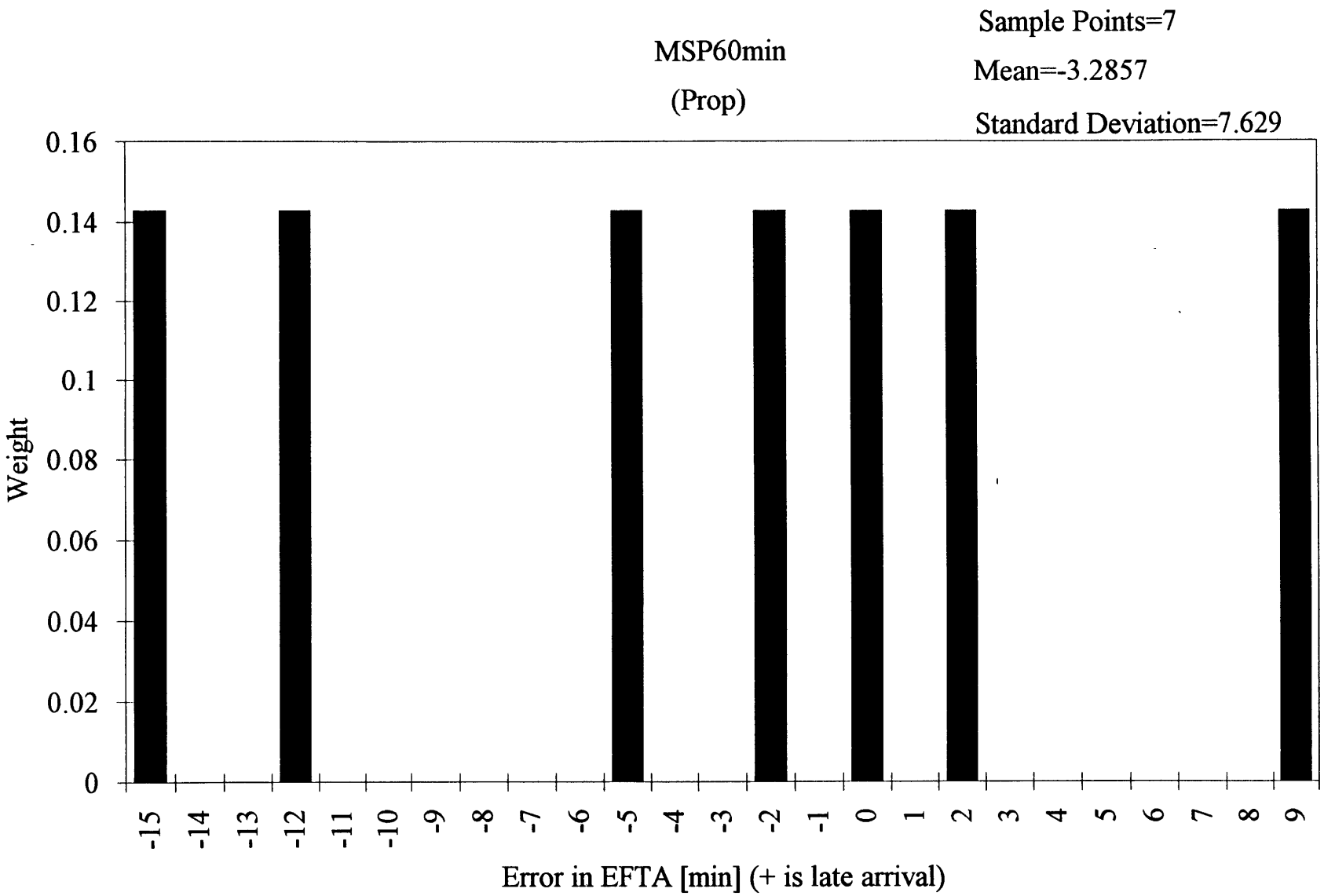


Fig.3.3.3g Distribution of Errors in EFTA at 60min-MSP Flights

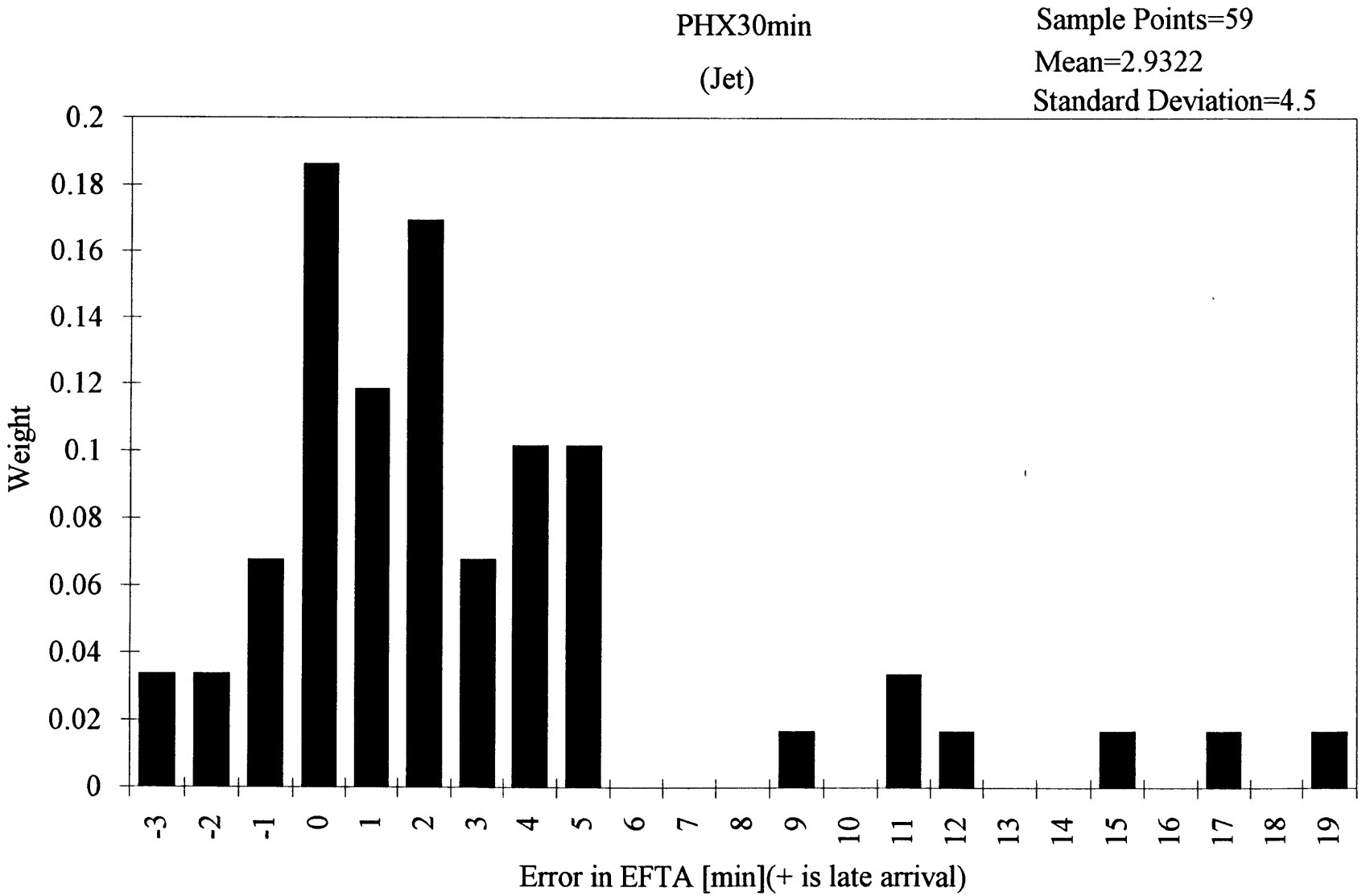


Fig.3.3.4a Distribution of Erroers in EFTA at 30min-PHX Flights

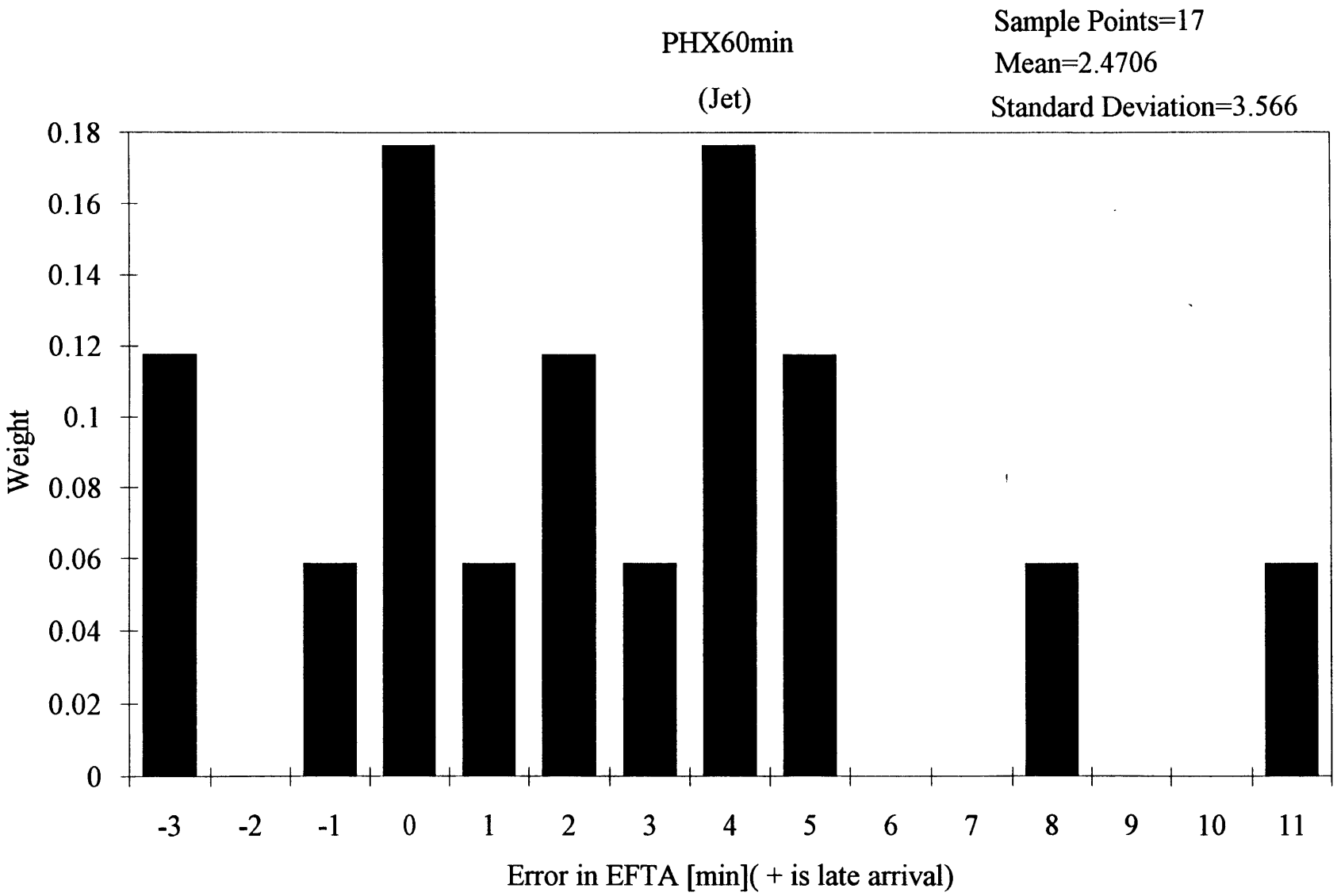


Fig.3.3.4b Distribution of Errors in EFTA at 60min-PHX Flights

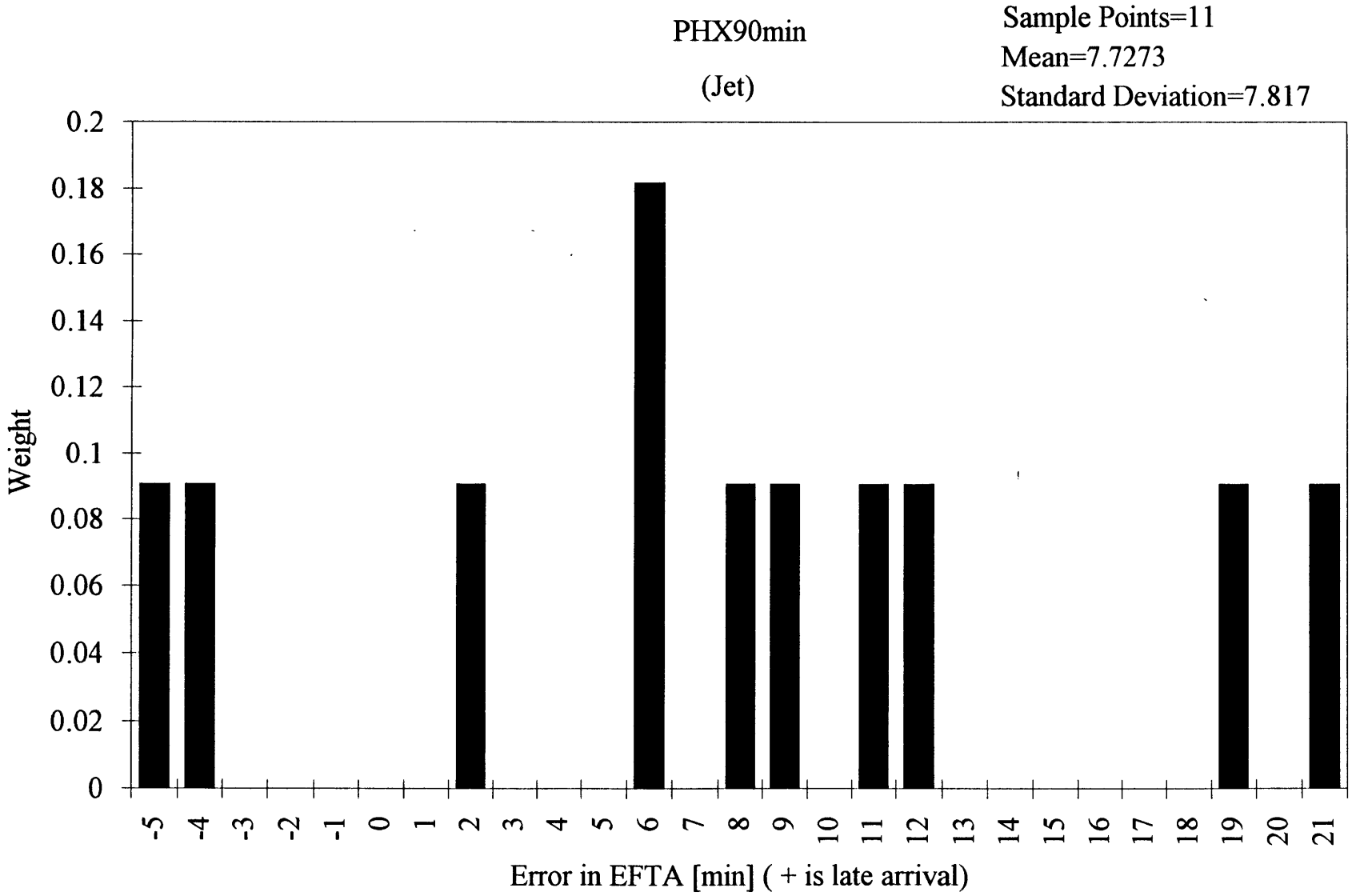


Fig.3.3.4c Distribution of Errors in EFTA at 90min-PHX Flights

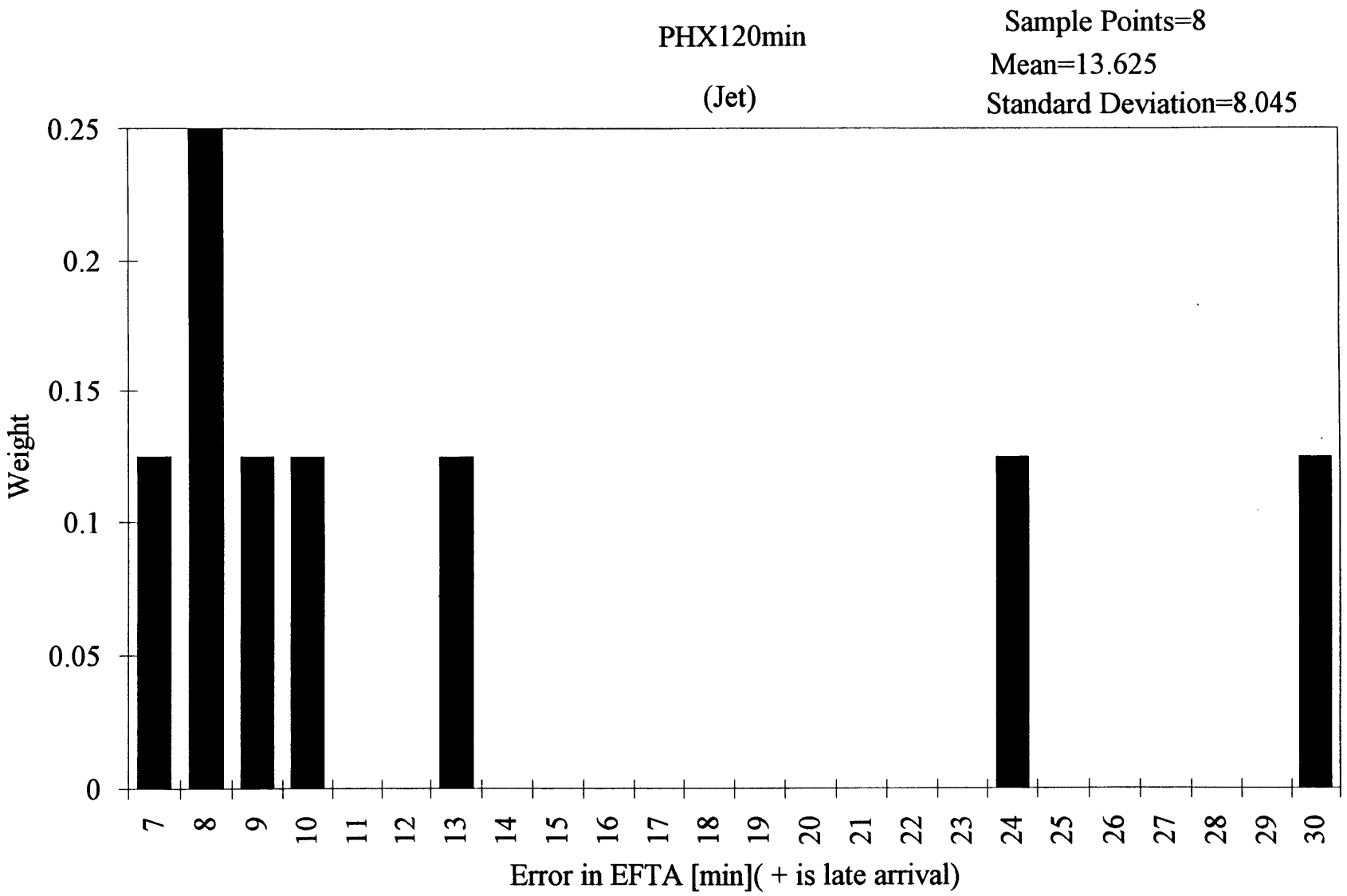


Fig.3.3.4d Distribution of Errors in EFTA at 120min-PHX Flights

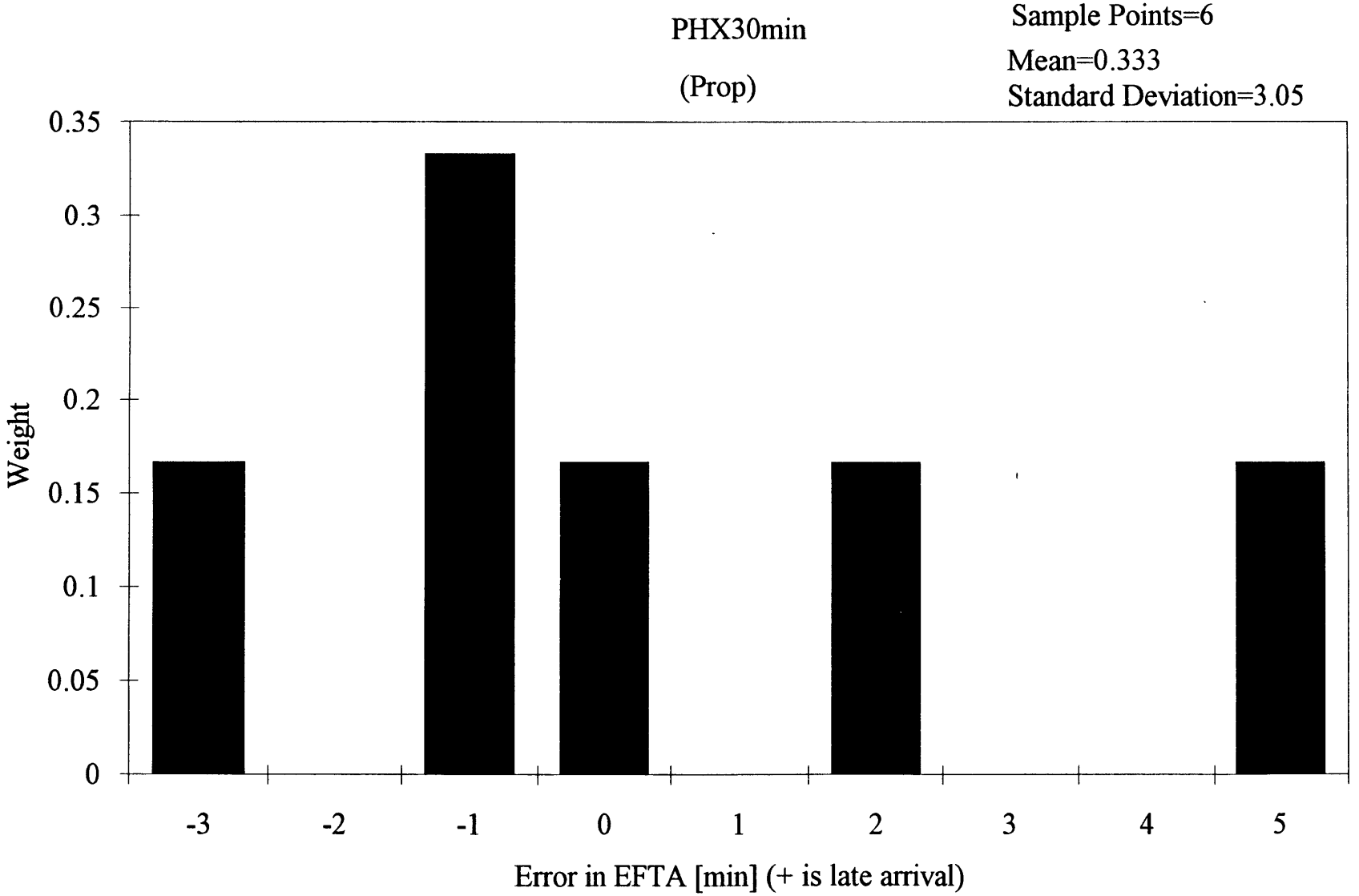


Fig.3.3.4e Distribution of Errors in EFTA at 30min-PHX Flights

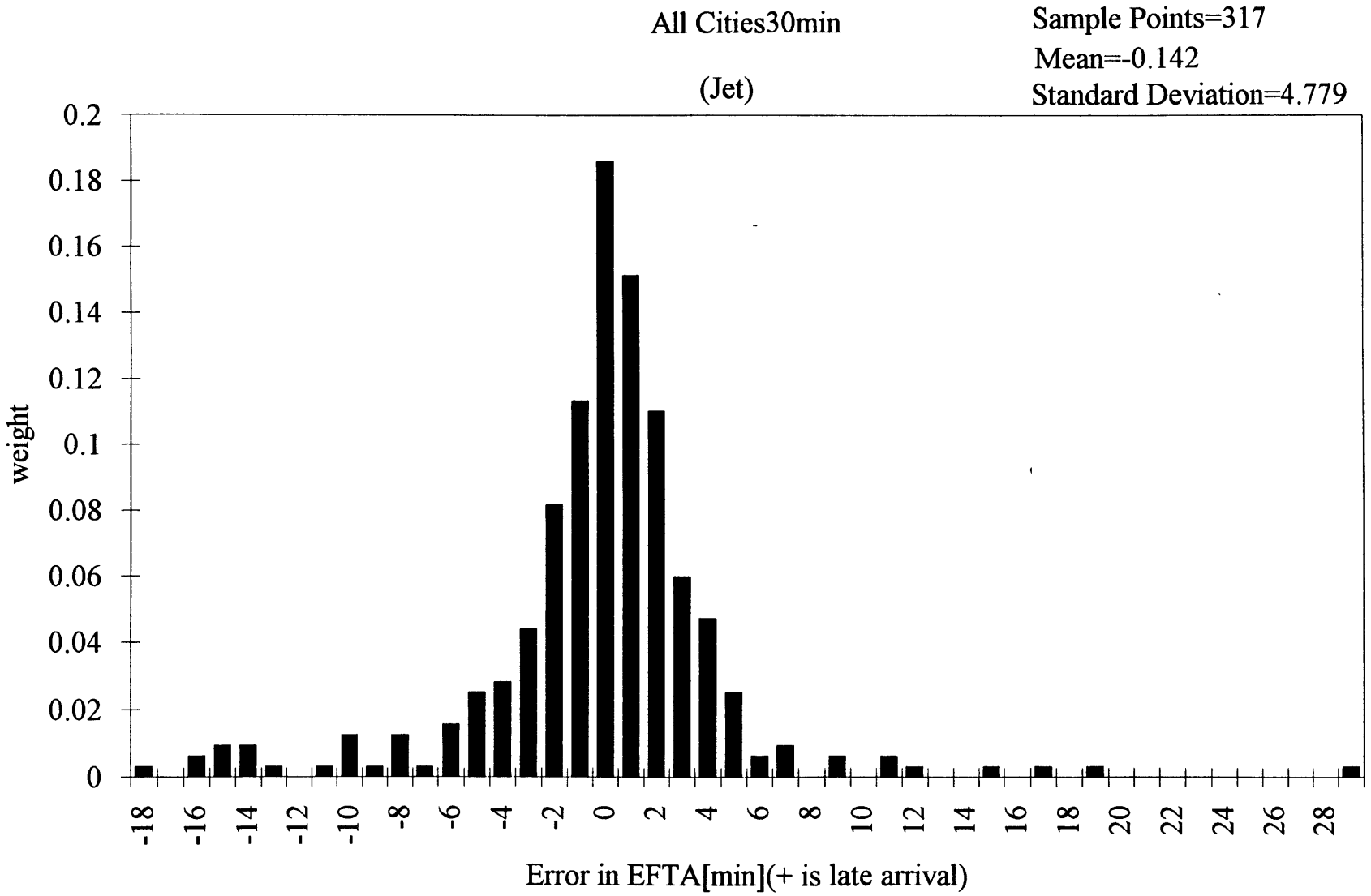


Fig.3.3.5a Distribution of Errors in EFTA at 30min-All Cities Flights

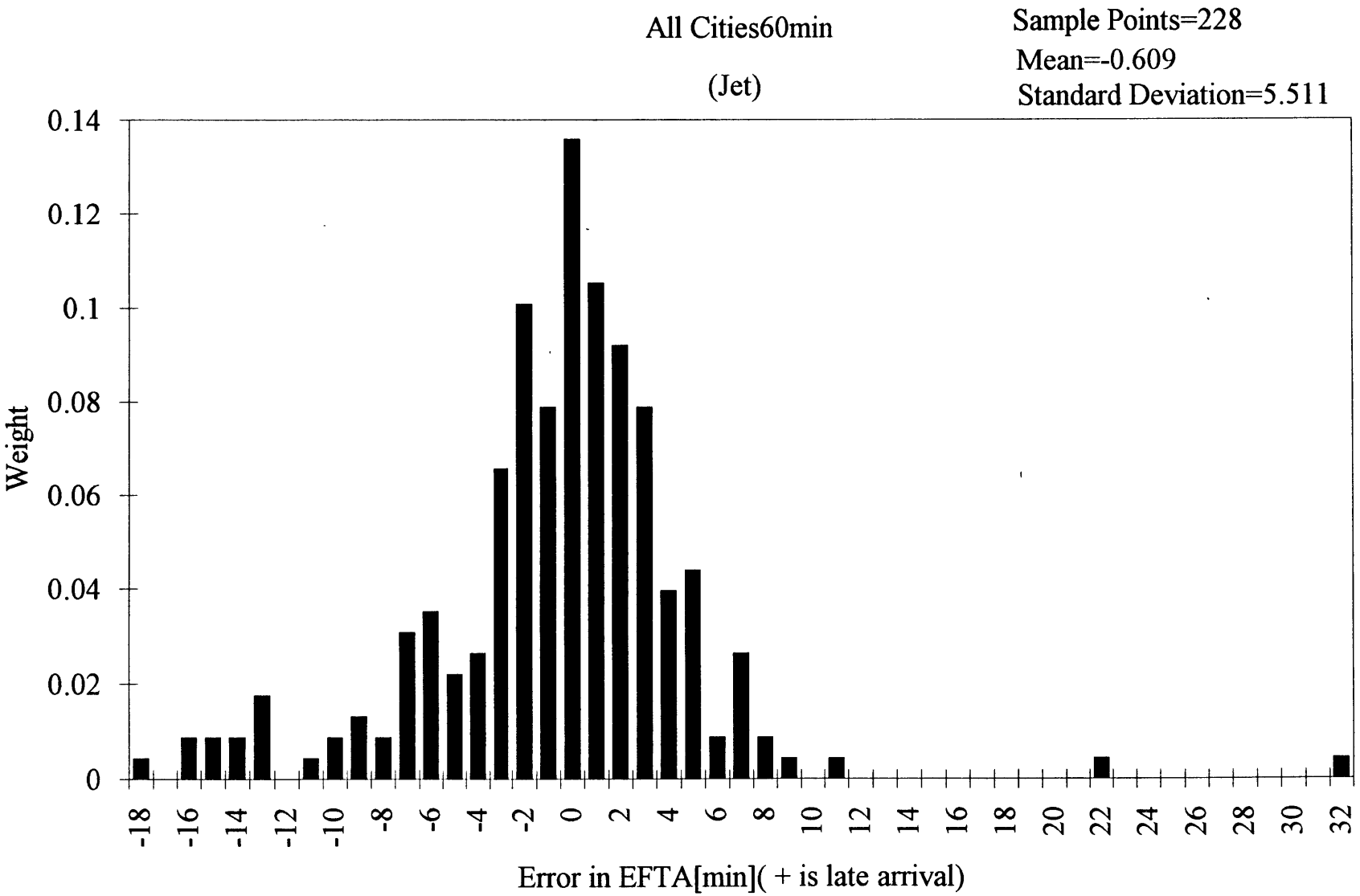


Fig.3.3.5b Distribution of Errors in EFTA at 60min-All Cities Flights

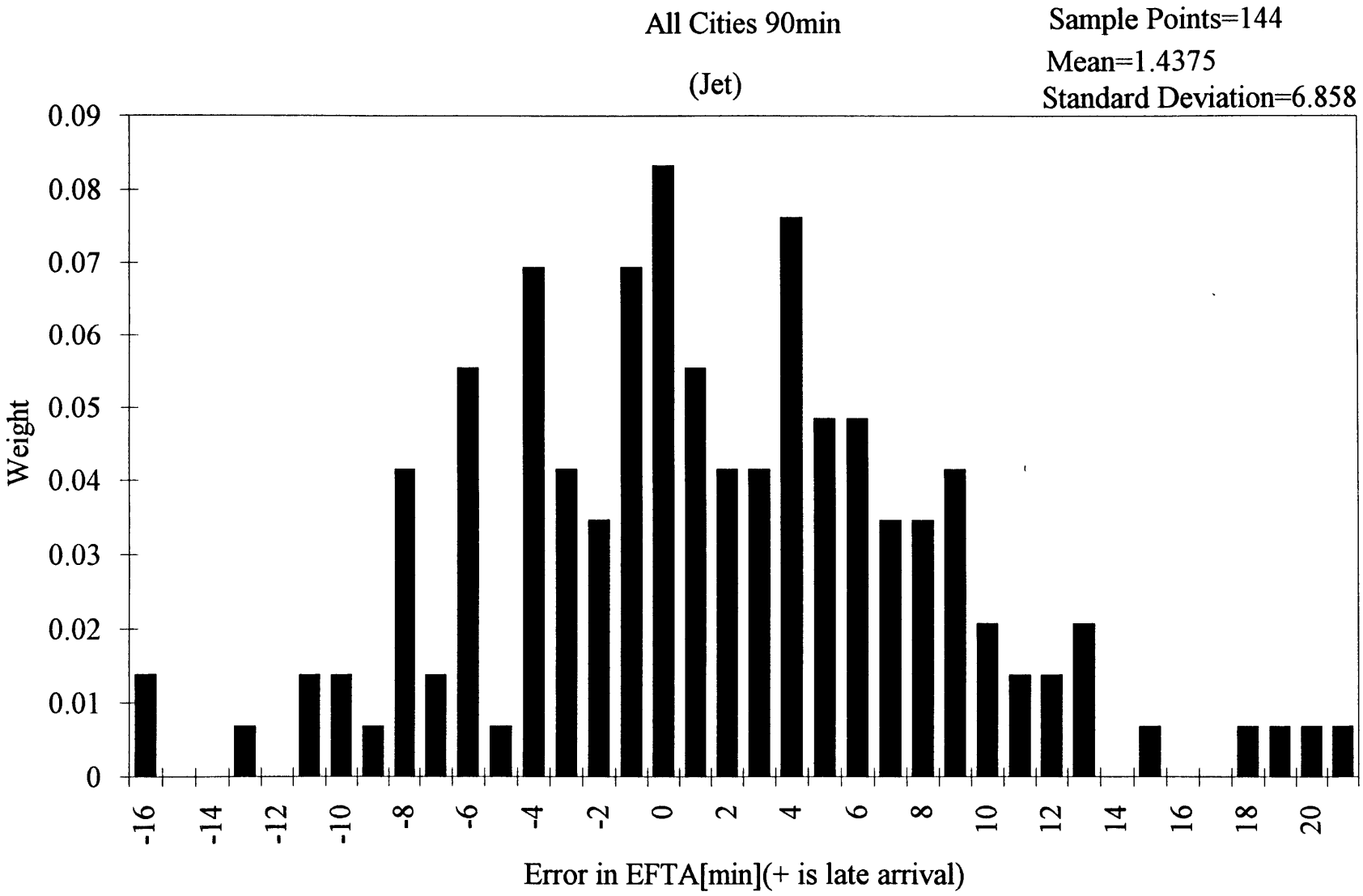


Fig.3.3.5c Distribution of Errors in EFTA at 90min-All Cities Flights

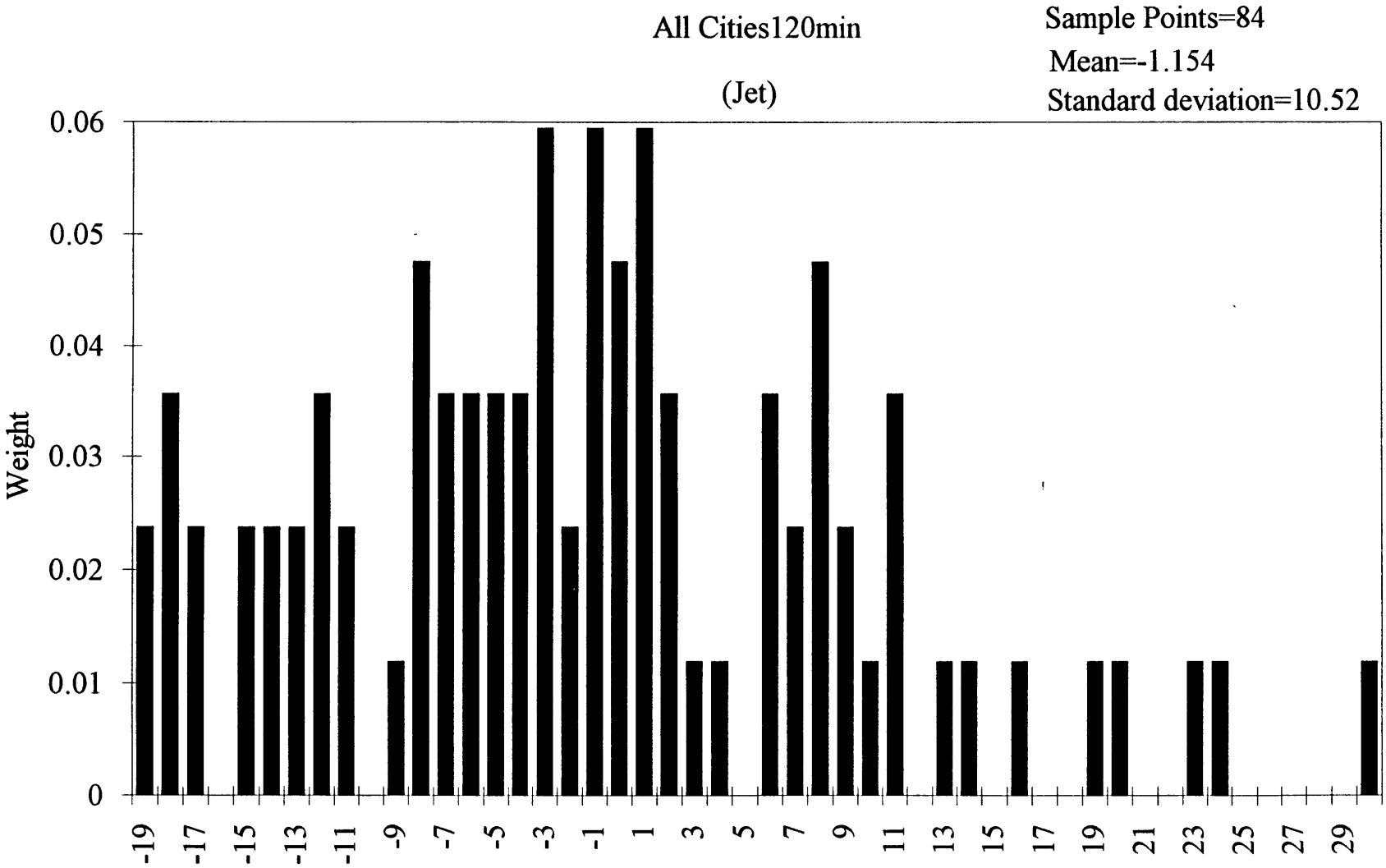


Fig.3.3.5d Distribution of Errors in EFTA at 120min-All Cities Flights

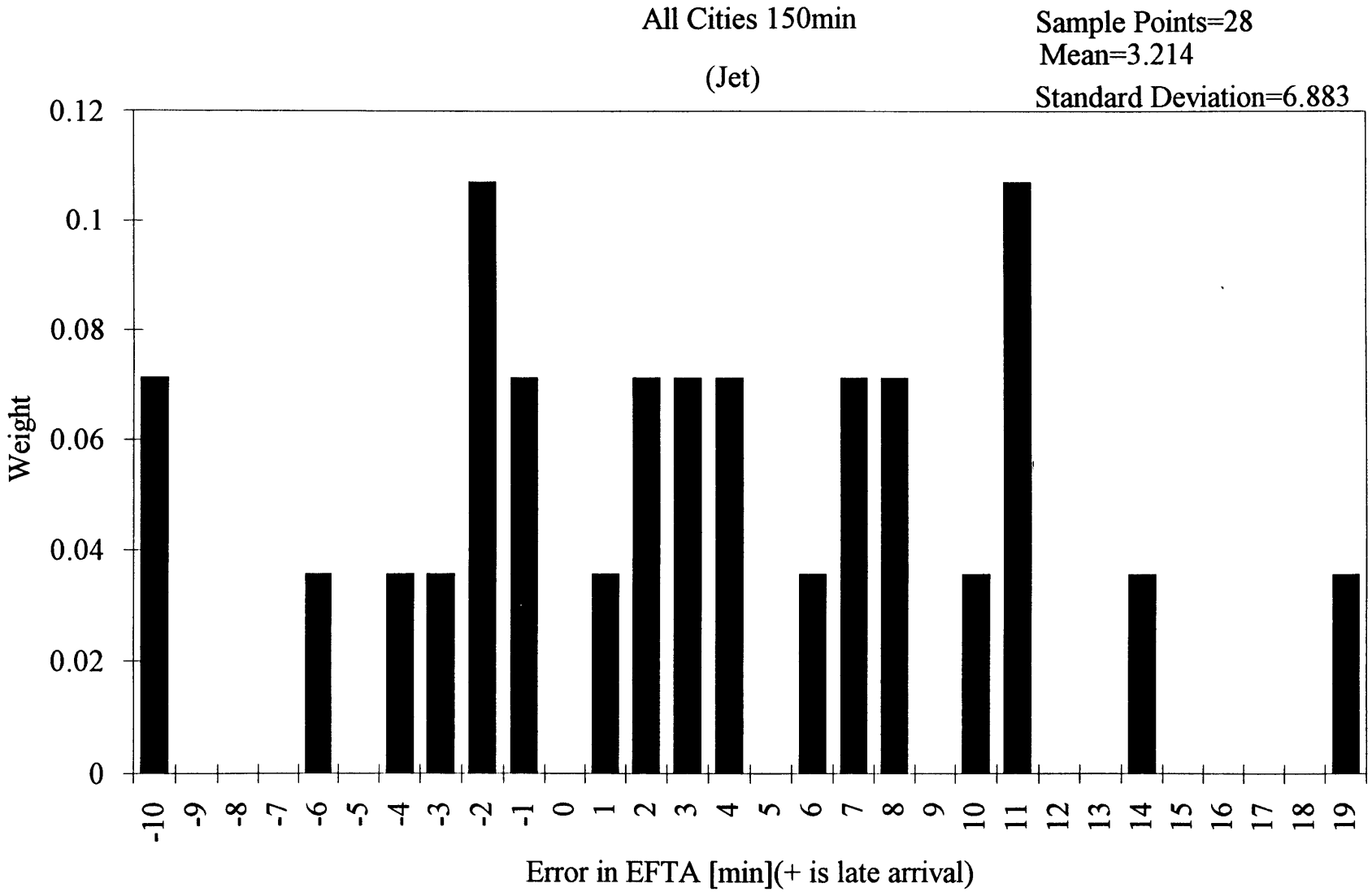


Fig. 3.3.5e Distribution of Errors in EFTA at 150min-All Cities Flights

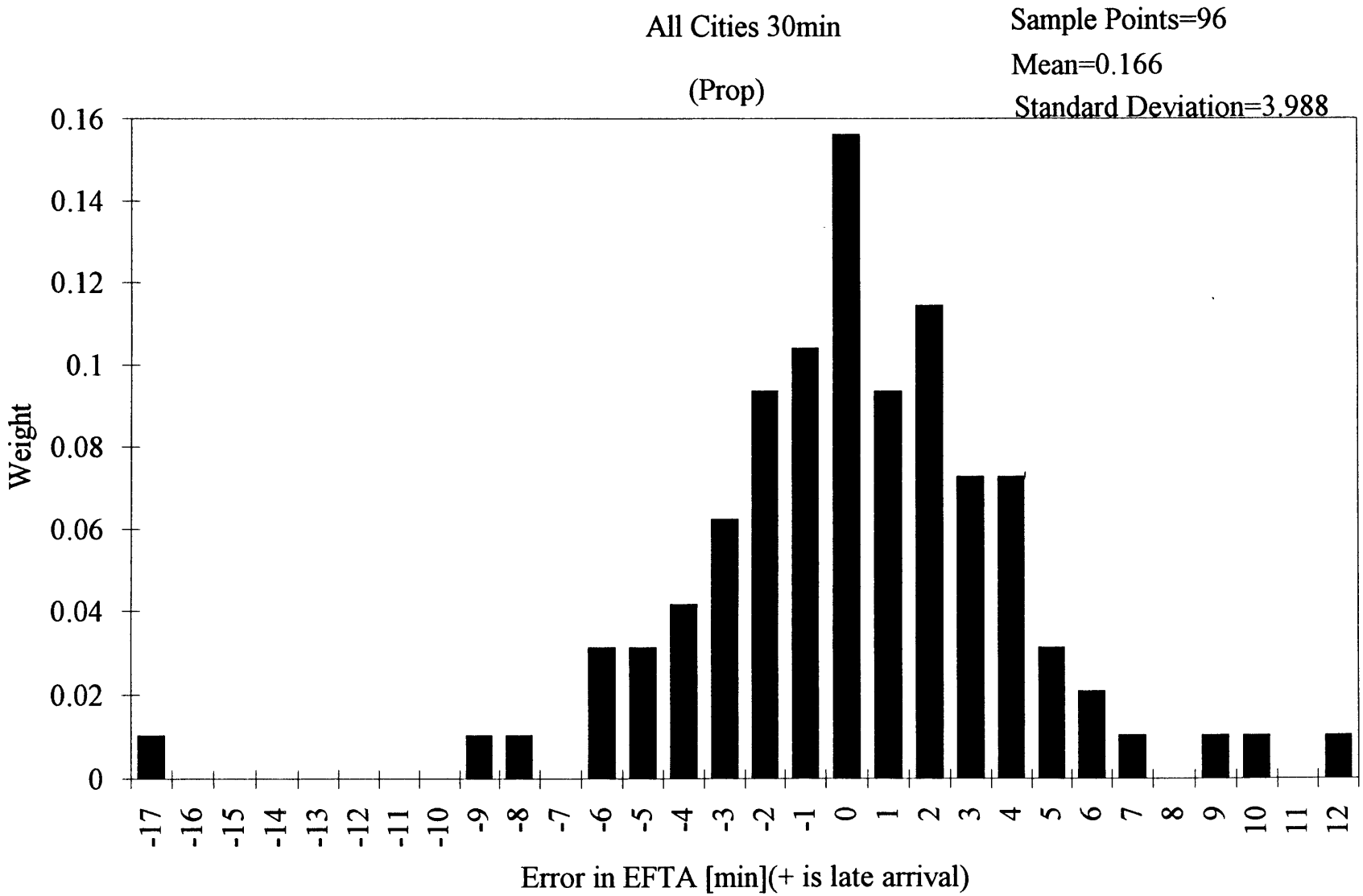


Fig.3.3.5f Distribution of Errors in EFTA at 30min-All Cities Flights

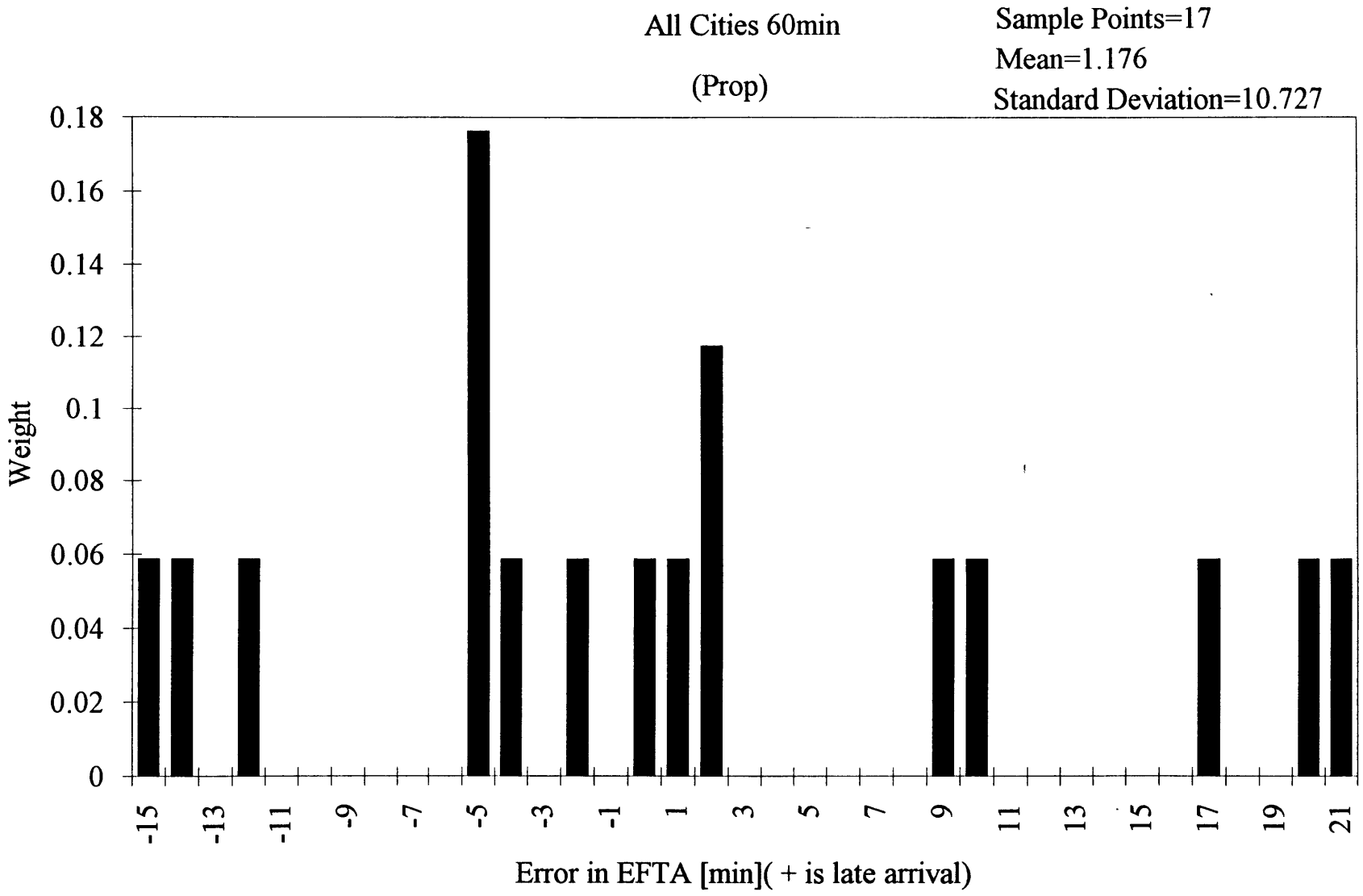


Fig.3.3.5g Distribution of Errors in EFTA at 60min-All Cities Flights

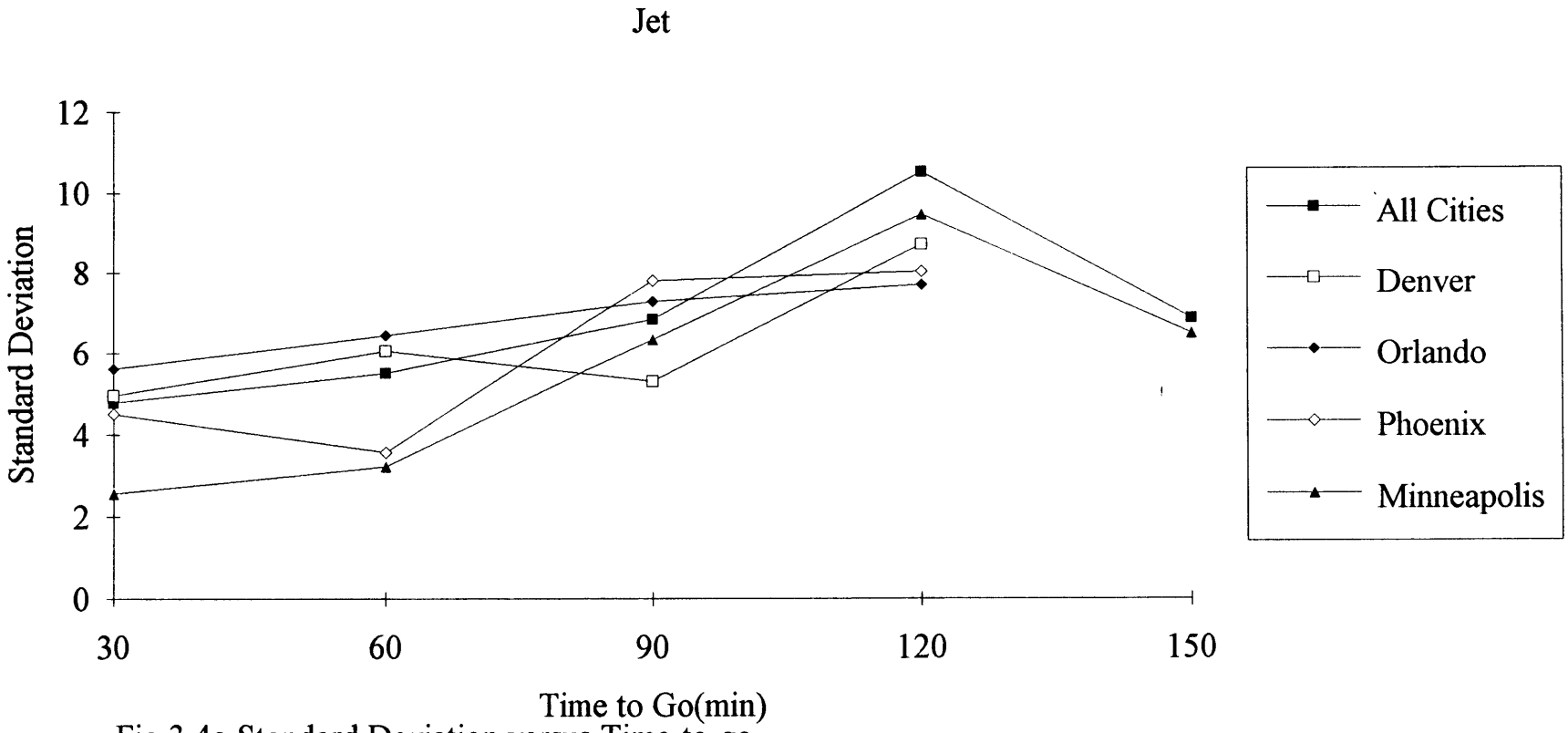


Fig.3.4a Standard Deviation versus Time-to-go

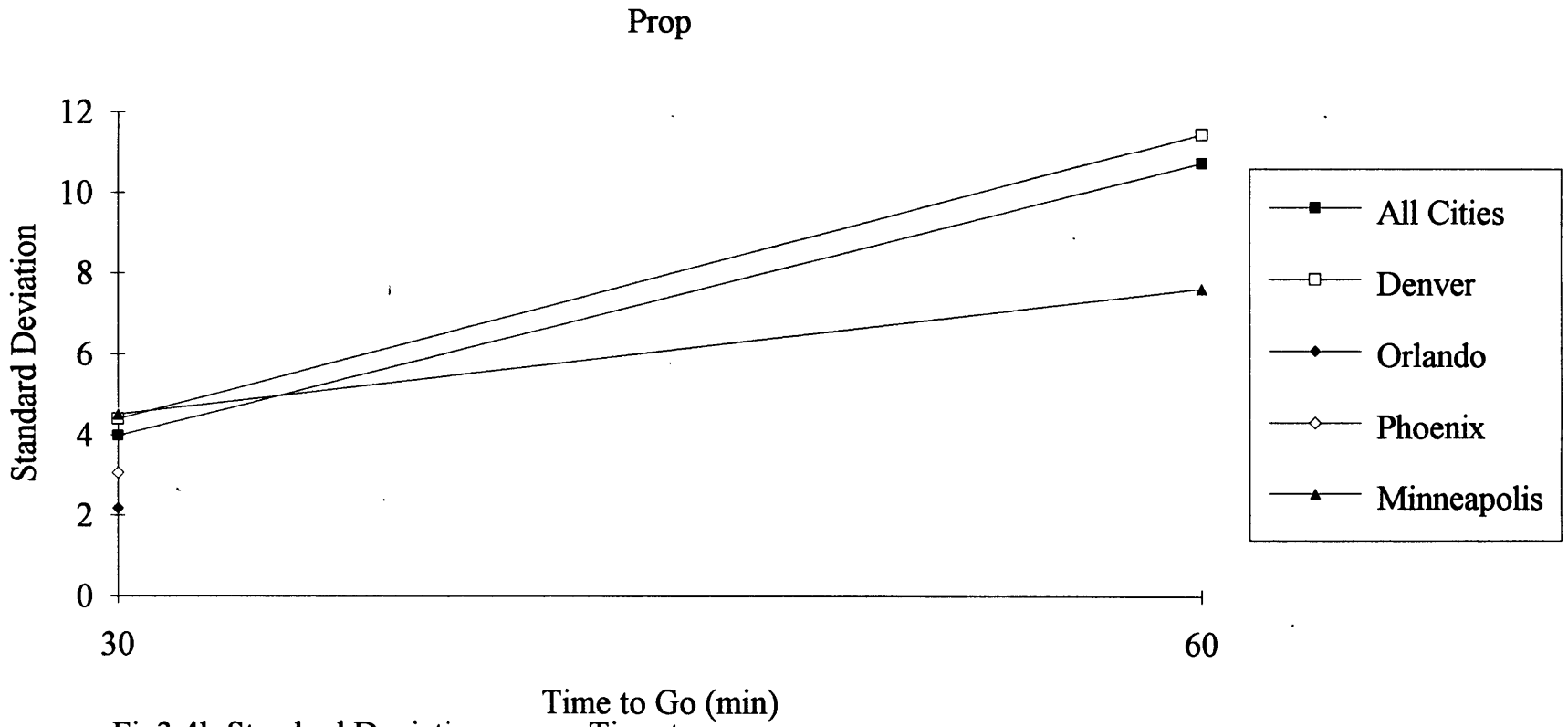


Fig3.4b Standard Deviation versus Time-to-go

Chapter 4

Analysis of Results

4.1 Introduction

The objective of this chapter is to analyze the results which we got in chapter 3 to evaluate which factors such as the numbers of sample points, or the effect of climbing influences over the EFTA errors and σ (standard deviation). Section 4.2 forwards the plot trends about the EFTA errors versus time to go for both jet and prop cases. Section 4.3 presents which factor influences the distribution of EFTA in Different Time-to-go Values. Section 4.4 provides the comparison results to prove the climbing does not really influence the σ (standard deviation) of the EFTA errors.

4.2 EFTA Errors versus Time-to-go (T)

From the results we got in Section 3.2, most of the EFTA error versus Time-to-go plots will converge to zero as Time-to-go T decreases. However, there are no consistent patterns for the plots. Take Fig.4.2 for example, the EFTA errors jumps(or drops) sharply

during the flight time and then decreases later as T decreases. Therefore, we conclude that there is no pattern for the EFTA error versus Time-to-go.

4.3 Distribution of EFTA Errors at Different Time-to-go

From Figs.3.3.1a to 3.3.5g, we see the number of sample points do really influence the distribution of EFTA error in different time periods. For all study cases, we can clearly see that for T=30,60 mins., since there are more sample points than other time periods, the distributions of ETA error are normally distributed. In contrast, for other time periods T=90,120,150 mins,etc., the distributions of the EFTA error are not as normal as what we expected. However, if we had more sample points for T=90,120 mins, etc., we can expect that the EFTA error distributions for them should be similar as what we got for T=30, 60 mins.

4.4 The Initial Climbing Effect on EFTA Error

To consider whether initial climbing affects the EFTA error, we consider those sample points for T=30 and 60 mins which are in the first 5 points of the flight during the time, since we suppose that in the first 25 mins, the flight is climbing. The comparisons are listed as follows:

Case 1: T=30 mins

σ=4.78 mins

Mean=-0.142

for all sample points of any flight.

σ=4.25 mins

Mean=0.96

for the points are in first five sample points of any flight.

σ=4.78 mins

Mean=-0.825

for the points are not in the first 5 sample points of any flight.

Case2: T=60 mins

σ=5.51 mins

Mean=-0.609

for all sample points of any flight.

σ=5.33 mins

Mean=-0.846

for the points are in first five sample points of any flight

σ=4.95 mins

Mean=-0.72

for the points are not in the first 5 sample points of any flight

The plots for above study cases can be seen in Tables 4.4a to 4.4f and Figs. 4.4a to 4.4f. From the results, we conclude that the climbing does not really affect the mean value or uncertainity of the EFTA error. This is an important result from this thesis.

Number#	Item	Ratio
1	-18	0.003154574
0	-17	0
2	-16	0.006309148
3	-15	0.009463722
3	-14	0.009463722
1	-13	0.003154574
0	-12	0
1	-11	0.003154574
4	-10	0.012618297
1	-9	0.003154574
4	-8	0.012618297
1	-7	0.003154574
5	-6	0.015772871
8	-5	0.025236593
9	-4	0.028391167
14	-3	0.044164038
26	-2	0.082018927
36	-1	0.113564669
59	0	0.186119874
48	1	0.151419558
35	2	0.110410095
19	3	0.059936909
15	4	0.047318612
8	5	0.025236593
2	6	0.006309148
3	7	0.009463722
0	8	0
2	9	0.006309148
0	10	0
2	11	0.006309148
1	12	0.003154574
0	13	0
0	14	0
1	15	0.003154574
0	16	0
1	17	0.003154574
0	18	0
1	19	0.003154574
0	20	0
0	21	0
0	22	0
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
1	29	0.003154574
Mean	-0.142	
Standard Deviation	4.779229513	
Variance	22.84103474	
Total#	317	

Table4.4a Distribution of Errors in EFTA at 30min-All Citiies Flights

Number#	Item	Ratio
1	-8	0.00952381
0	-7	0
3	-6	0.028571429
3	-5	0.028571429
2	-4	0.019047619
9	-3	0.085714286
7	-2	0.066666667
12	-1	0.114285714
20	0	0.19047619
8	1	0.076190476
13	2	0.123809524
7	3	0.066666667
6	4	0.057142857
5	5	0.047619048
1	6	0.00952381
2	7	0.019047619
0	8	0
1	9	0.00952381
0	10	0
2	11	0.019047619
1	12	0.00952381
0	13	0
0	14	0
0	15	0
0	16	0
1	17	0.00952381
0	18	0
1	19	0.00952381
Mean	0.9619	
Standard Deviation	4.251440743	
Variance	18.07474839	
Total#	105	

The chosen points are in the first 5 points

Table4.4b Distribution of Errors in EFTA at 30min-All Cities Flights

Number#	Item	Ratio
1	-18	0.004716981
0	-17	0
2	-16	0.009433962
3	-15	0.014150943
3	-14	0.014150943
1	-13	0.004716981
0	-12	0
1	-11	0.004716981
4	-10	0.018867925
1	-9	0.004716981
3	-8	0.014150943
1	-7	0.004716981
2	-6	0.009433962
5	-5	0.023584906
8	-4	0.037735849
5	-3	0.023584906
19	-2	0.089622642
24	-1	0.113207547
40	0	0.188679245
42	1	0.198113208
22	2	0.103773585
11	3	0.051886792
8	4	0.037735849
2	5	0.009433962
1	6	0.004716981
1	7	0.004716981
0	8	0
1	9	0.004716981
0	10	0
0	11	0
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
0	22	0
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
1	29	0.004716981
Mean	-0.825	
Standard Deviation	4.783377024	
Variance	22.88069575	
Total#	212	

The chosen points are not in the first 5 points

Table4.4c Distribution of Errors in EFTA at 30min-All Cities Flight

Number#	Item	Ratio
1	-18	0.004385965
0	-17	0
2	-16	0.00877193
2	-15	0.00877193
2	-14	0.00877193
4	-13	0.01754386
0	-12	0
1	-11	0.004385965
2	-10	0.00877193
3	-9	0.013157895
2	-8	0.00877193
7	-7	0.030701754
8	-6	0.035087719
5	-5	0.021929825
6	-4	0.026315789
15	-3	0.065789474
23	-2	0.100877193
18	-1	0.078947368
31	0	0.135964912
24	1	0.105263158
21	2	0.092105263
18	3	0.078947368
9	4	0.039473684
10	5	0.043859649
2	6	0.00877193
6	7	0.026315789
2	8	0.00877193
1	9	0.004385965
0	10	0
1	11	0.004385965
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
1	22	0.004385965
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
0	29	0
0	30	0
0	31	0
1	32	0.004385965
Mean	-0.609	
Standard Deviation	5.511725592	
Variance	30.379119	
Total#	228	

Table4.4d Distribution of Errors in EFTA at 60min-All Cities Flights

Number#	Item	Ratio
1	-18	0.012820513
0	-17	0
2	-16	0.025641026
0	-15	0
0	-14	0
0	-13	0
0	-12	0
0	-11	0
1	-10	0.012820513
0	-9	0
1	-8	0.012820513
3	-7	0.038461538
3	-6	- 0.038461538
2	-5	0.025641026
3	-4	0.038461538
8	-3	0.102564103
6	-2	0.076923077
6	-1	0.076923077
9	0	0.115384615
10	1	0.128205128
8	2	0.102564103
7	3	0.08974359
1	4	0.012820513
3	5	0.038461538
0	6	0
0	7	0
1	8	0.012820513
1	9	0.012820513
0	10	0
0	11	0
0	12	0
0	13	0
0	14	0
0	15	0
0	16	0
0	17	0
0	18	0
0	19	0
0	20	0
0	21	0
1	22	0.012820513
0	23	0
0	24	0
0	25	0
0	26	0
0	27	0
0	28	0
0	29	0
0	30	0
0	31	0
1	32	0.012820513
Mean	-0.846	
Standard Deviatio	5.339948804	
Variance	28.51505323	
Total#	78	

The chosen points are in the first 5 points

Table4.4e Distribution of Errors in EFTA at 60min-All Cities Flight

Number#	Item	Ratio
2	-15	0.013333333
2	-14	0.013333333
5	-13	0.033333333
0	-12	0
1	-11	0.006666667
1	-10	0.006666667
3	-9	0.02
1	-8	0.006666667
4	-7	0.026666667
3	-6	0.02
3	-5	0.02
3	-4	0.02
7	-3	0.046666667
17	-2	0.113333333
11	-1	0.073333333
23	0	0.153333333
15	1	0.1
13	2	0.086666667
12	3	0.08
8	4	0.053333333
7	5	0.046666667
2	6	0.013333333
5	7	0.033333333
1	8	0.006666667
0	9	0
0	10	0
1	11	0.006666667
Mean	-0.72	
Standard Deviation	4.957311099	
Variance	24.57493333	
Total#	150	

The chosen points are not in the first 5 points

Table4.4f Distribution of Errors in EFTA at 60min-All Cities Flights

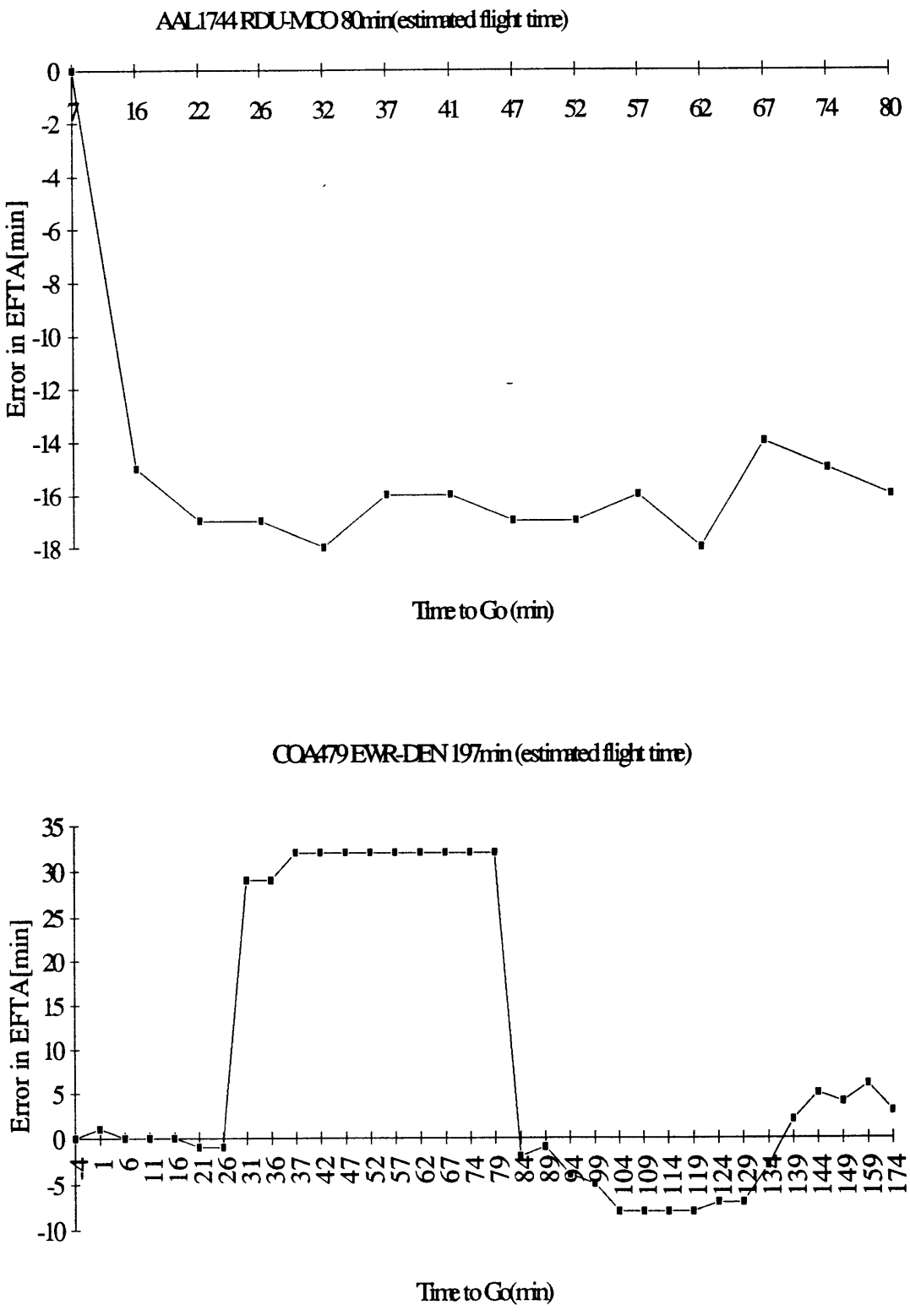


Fig.4.2 Sample Histories of Estimation Errors

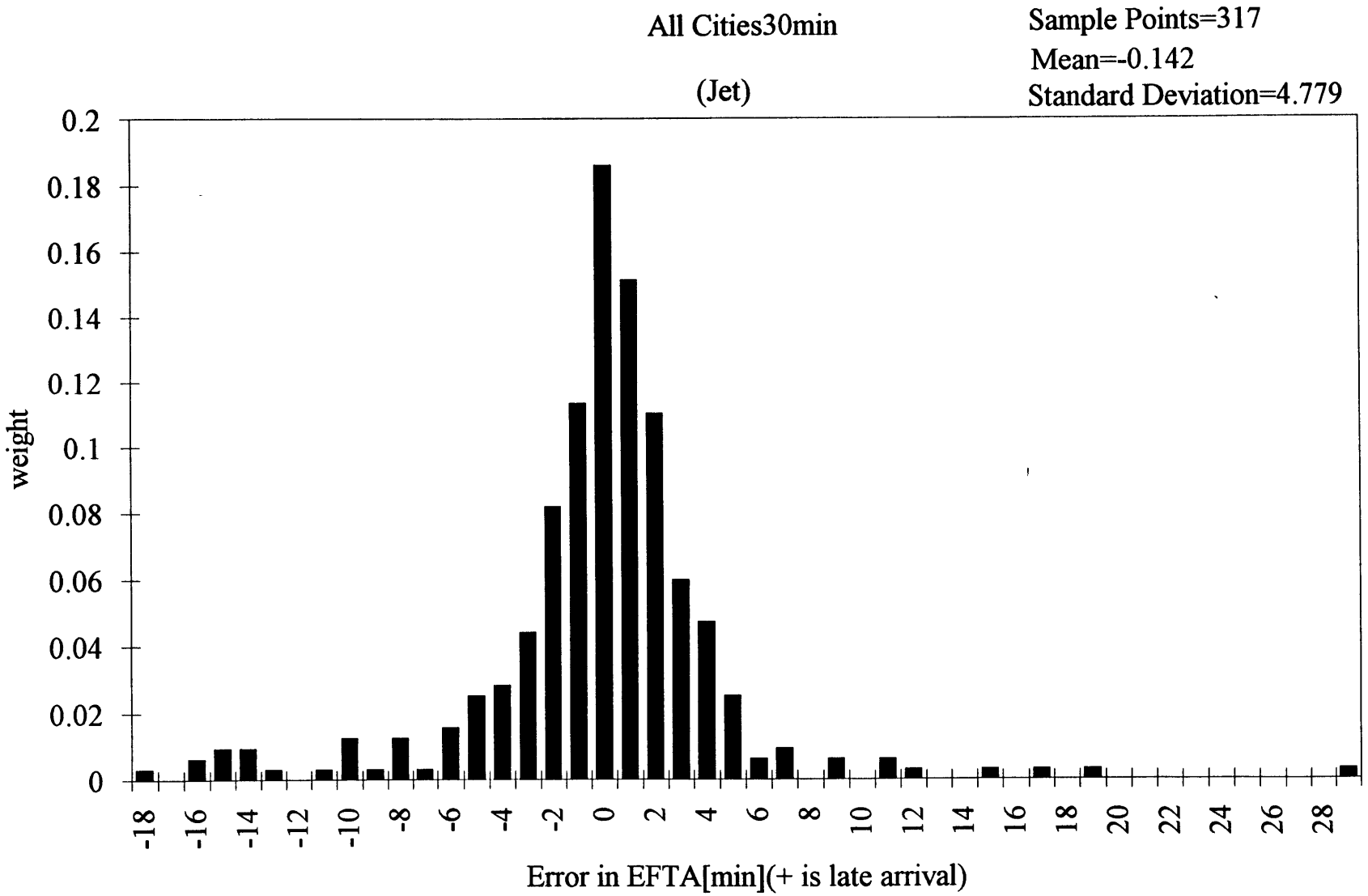


Fig.4.4a Distribution of Errors in EFTA at 30min-All Cities Flights

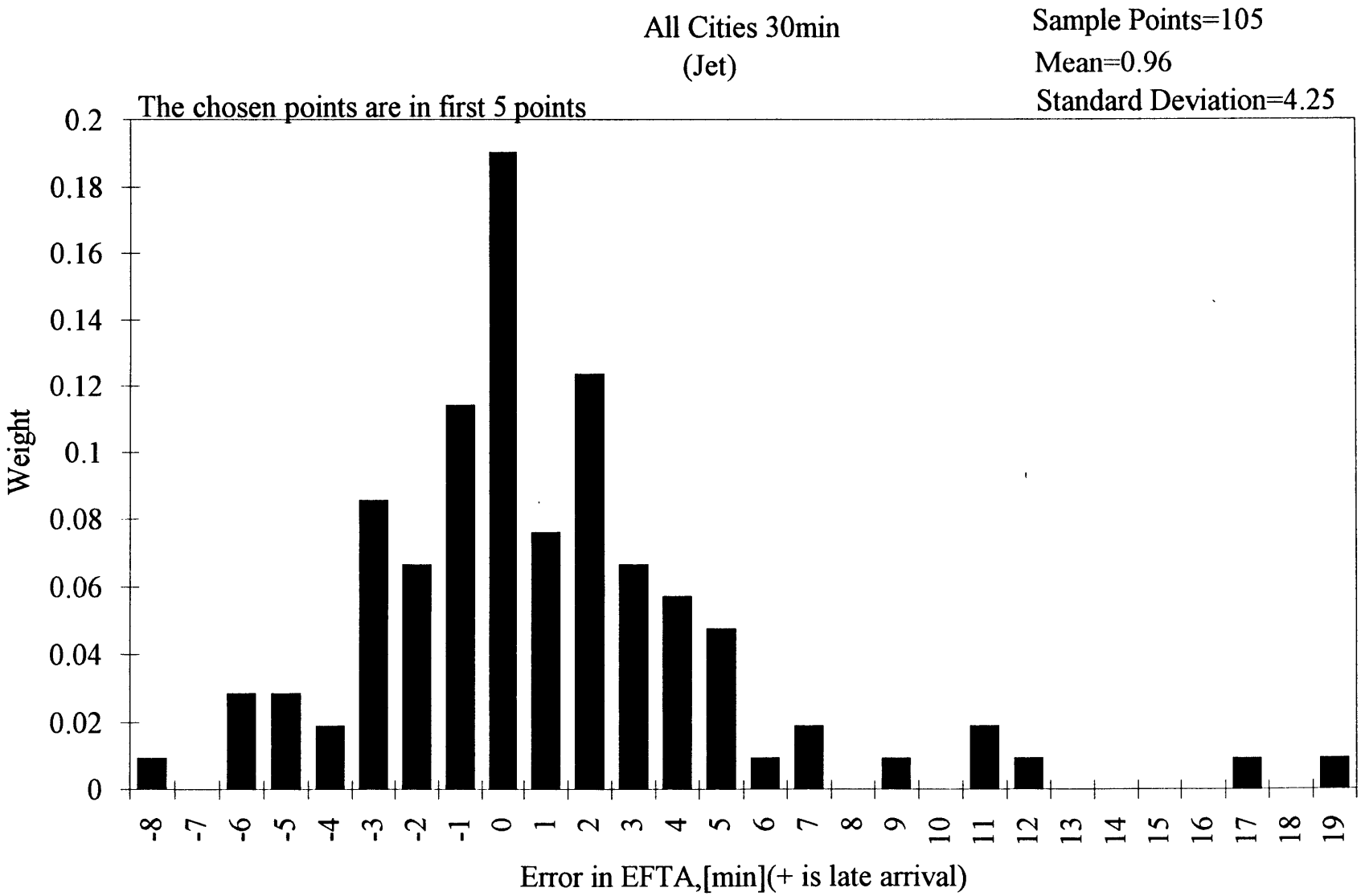


Fig.4.4b Distribution of Errors in EFTA at 30min-All Cities Flights

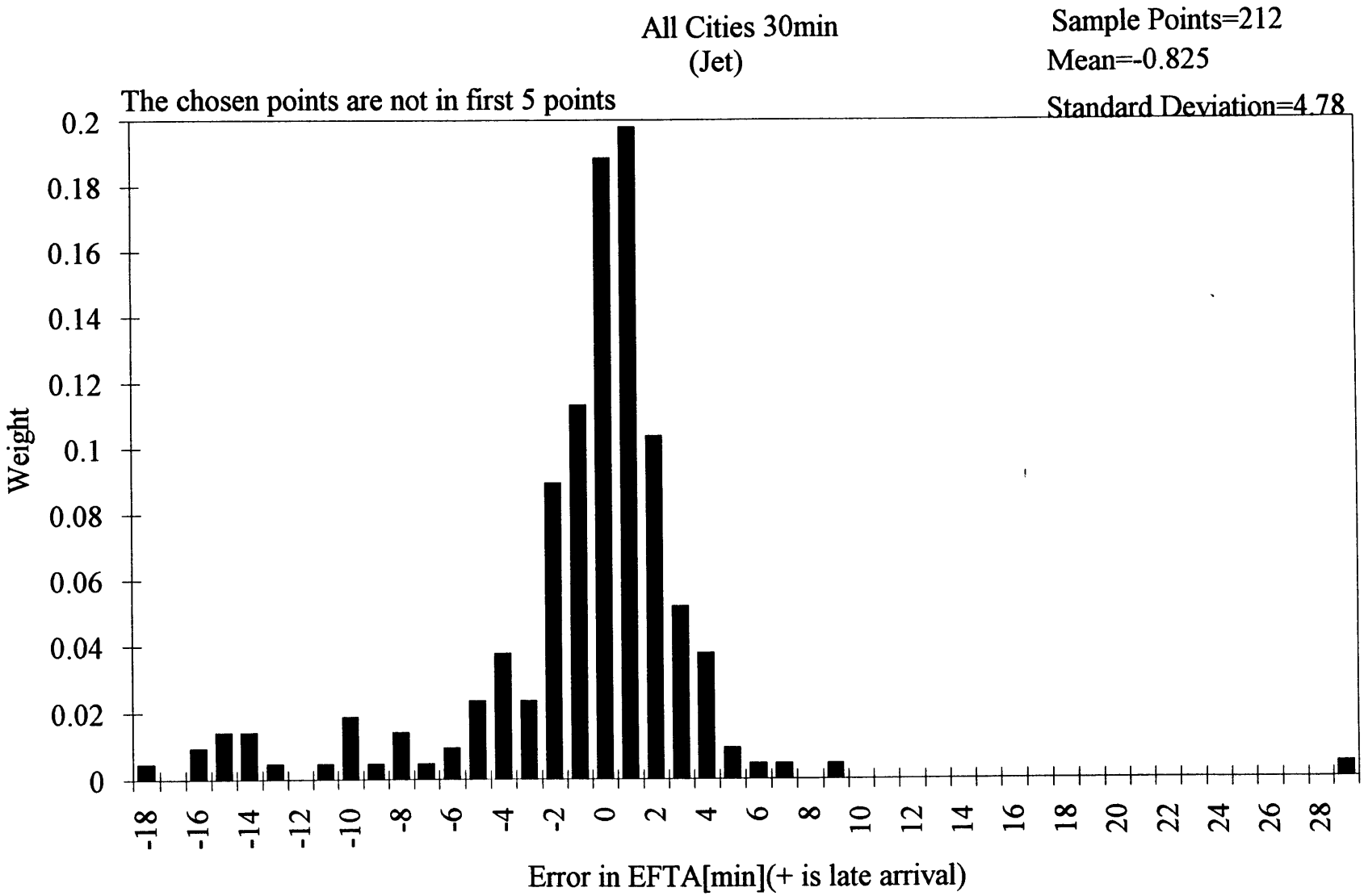


Fig.4.4c Distribution of Errors in EFTA at 30min-All Cities Flights

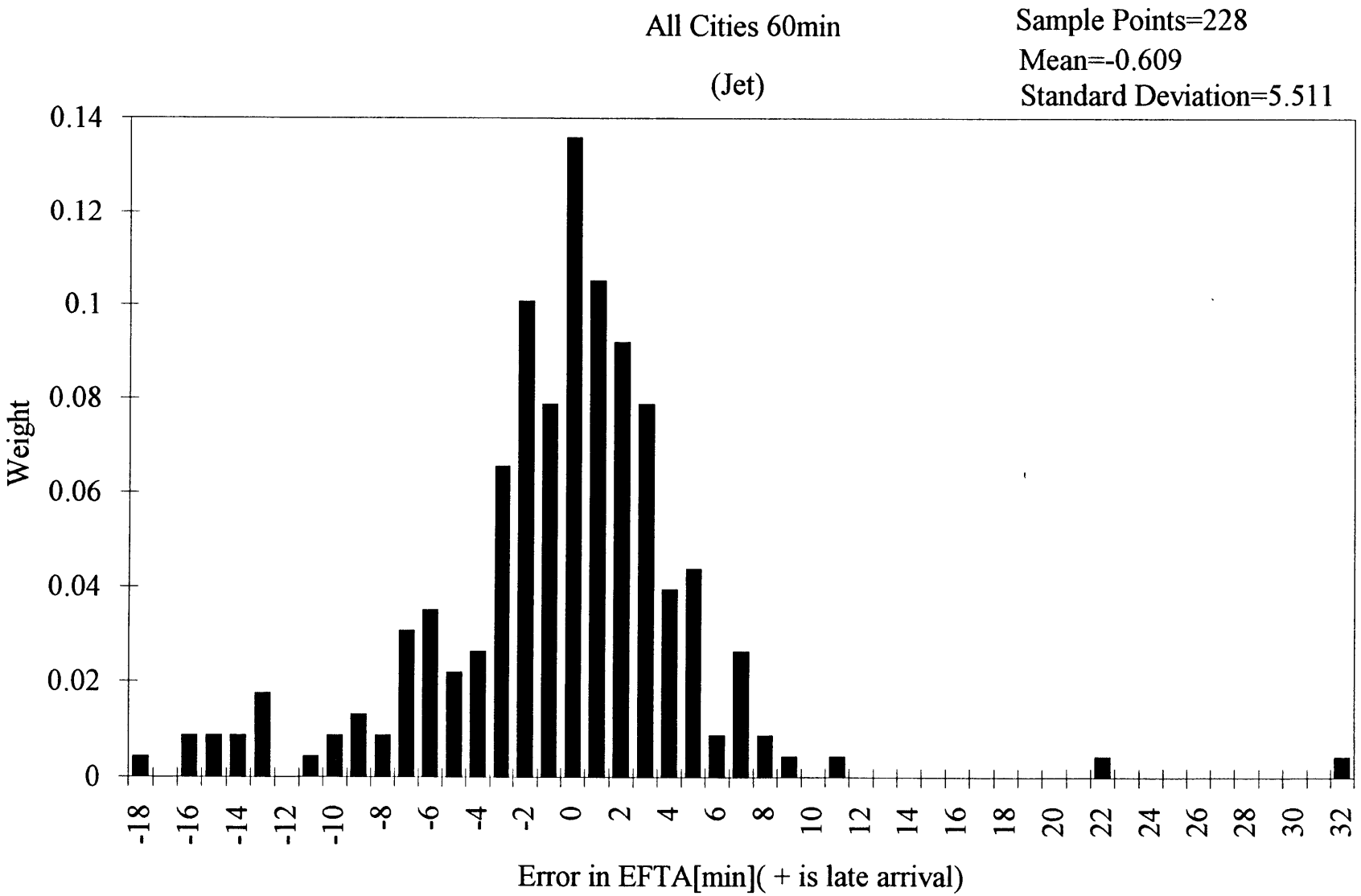


Fig.4.4dDistribution of Errors in EFTA at 60min-All Cities Flights

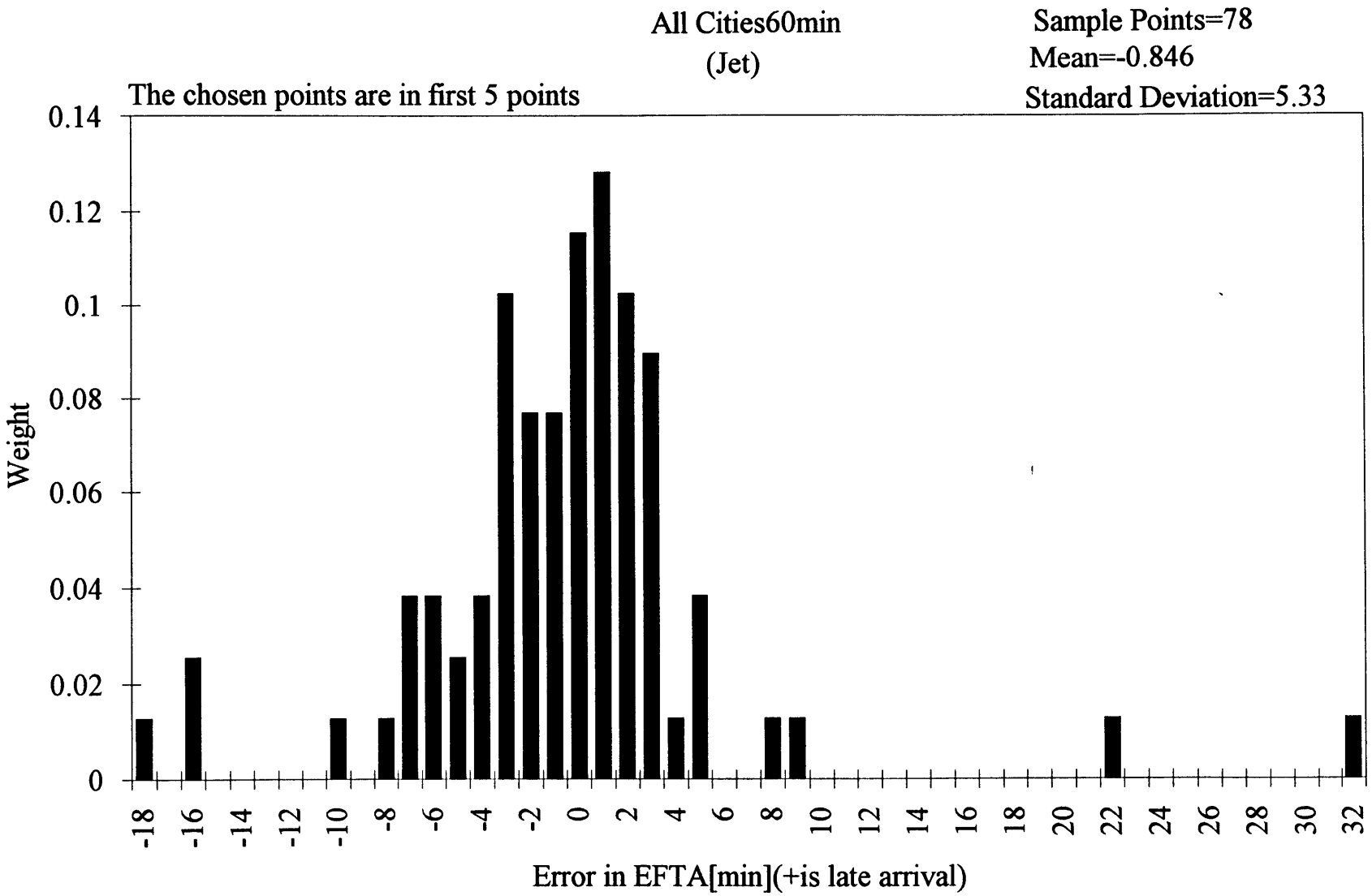


Fig.4.4e Distribution of Errors in EFTA at 60min-All Cities Flights

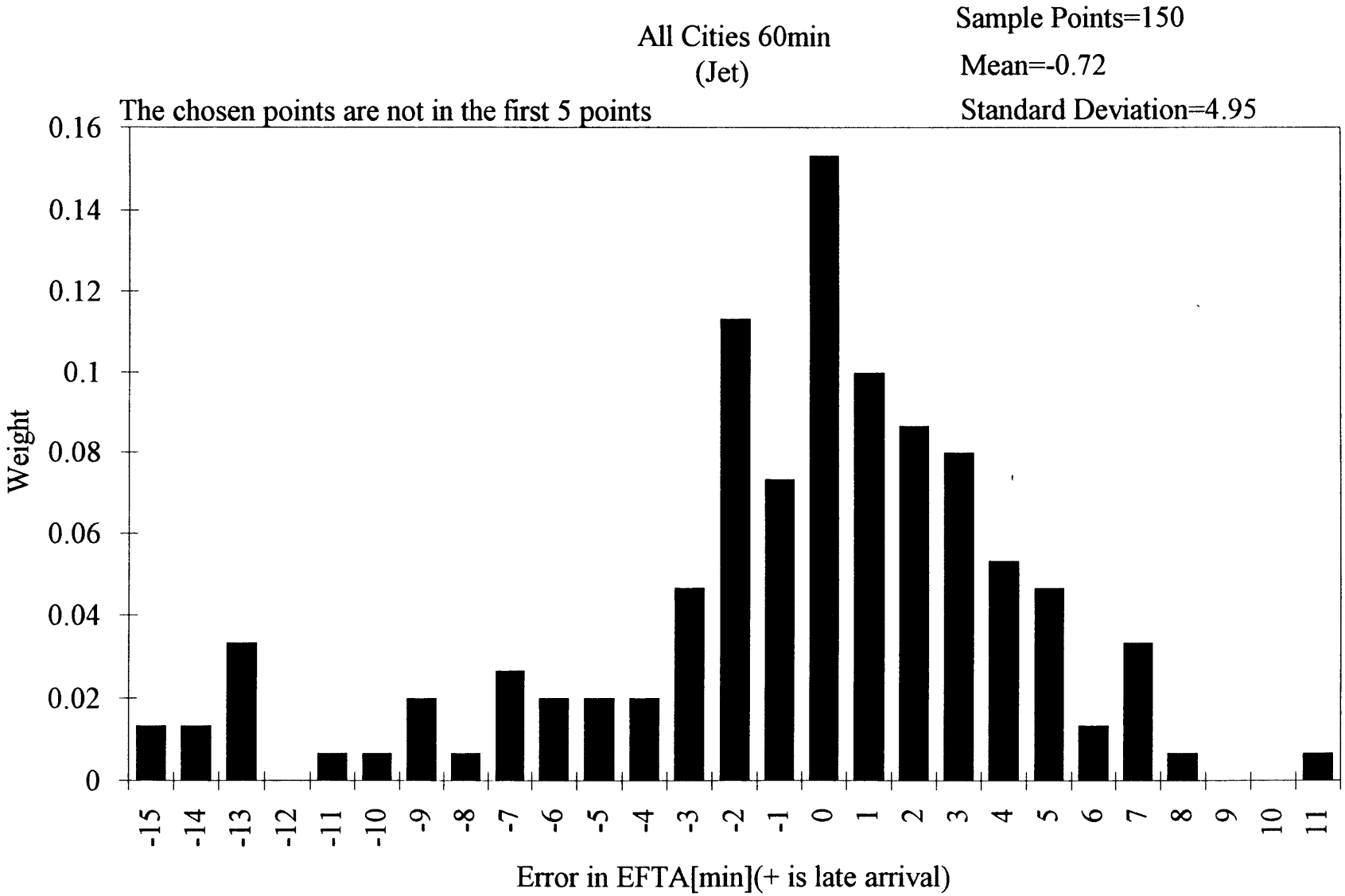


Fig.4.4f Distribution of Errors in EFTA at 60min-All Cities Flights

Chapter 5

Concluding Remarks

The objective of this study is to provide statistical evidence about the accuracy of Estimated Fix Time Arrivals (EFTAs) for airborne aircraft of terminal area entry fixes as a function of "Time to Go". This is needed to confirm the expected arrival rates at a congested airport.

First, a literature descriptions about Estimated Traffic Management System (ETMS) and some background referring to the National Airspace (NAS) messages, Time Type (TTP), and Flight Time Modeling are introduced.

Second, a study of the methodology used in the statistical analysis. It explains how to pick up sample points from flights into four cities (Denver, Orlando, Minneapolis, and Phoenix). And then using the data points we draw some example plots between EFTA errors versus Time to Go, the distribution of EFTA errors for different time period (T=30,60,90 mins, etc.), and the σ's variation with time.

Third, an analysis of the results we got in chapter 3, we reach three conclusions. The first is that there are no regular patterns for the EFTA errors versus Time-to-go. The second is if there are enough sample points considered in the plotting for the distribution of EFTA errors for different time periods, the shape of the distribution should be normally distributed. The last is that the climbing effect does not really affect the σ's variation with time.

5.1 Future Topics in this Field

For this study, we picked the TZ and AZ points to do the distribution of EFTA Error, and its standard deviation versus Time-to-go. We expect more analysis on the distribution of EFTA errors for the initial FZ and FS points. It is desirable to try to obtain information on airspeed or groundspeed to see if we can identify the imposition of "miles-in-trail" during the flight. (This would cause a slow down and a sudden increase in EFTA-this can be seen in some of the EFTA profiles) There are also some EFTA profiles which indicate a delay in arrival over the last 10 or 15 minutes of the flight which might be explained by the imposition of airborne holding near the destination airport. It is desirable to see if such "holding" can be confirmed. This thesis has been on initial look at EFTA errors, and the results are perhaps limited by the number of sample points. For this reason, further research might be undertaken using more data particularly for the long haul flights.