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A CORRELATION AND FORECASTING  
ANALYSIS ON LOST SATELLITES

THESIS

Kenneth R. Norton

Captain, USAF

AFIT/GSO/ENS/90D-13

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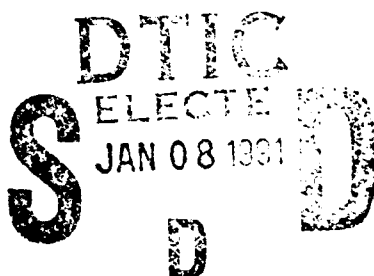
**AIR FORCE INSTITUTE OF TECHNOLOGY**

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A CORRELATION AND FORECASTING ANALYSIS  
ON LOST SATELLITES

THESIS

Presented to the Faculty of the School of Engineering  
of the Air Force Institute of Technology

Air University

In partial Fulfillment of the  
Requirements for the Degree of  
Master of Science in Space Operations

Kenneth R. Norton, B.S.

Captain, USAF

December, 1990

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## Preface

The purpose of this study is to investigate the relationship between Space Command's Space Surveillance Center's (SSC) number of near earth lost satellites and solar activity, geomagnetic field strength, crew activity and number of sensor observations arriving into the SSC. The first task is to obtain the longest duration of data from the SSC, with the least number of gaps, to use in computations. In investigating the relationship between the number of near earth lost satellites and both solar activity and the number of sensor observations both simple and multiple regression techniques are undertaken to determine the correlation. Next multiple linear regression, time series and naive forecast 1 are used to build forecast models.

The goal of this thesis is to accomplish two things. First, because of the my prior experience in the SSC, I am very interested in learning what variables influence the number of lost satellites. Secondly, to find the best model for predicting the number of lost satellites.

In my attempt to finish this thesis I received assistance from several people to whom I am greatly indebted. First and foremost is my advisor Lieutenant Colonel Robinson. Lieutenant Colonel Robinson's understanding of space operations, his encouragement, and his ability to keep my thesis efforts focused have been key to completion of

this project. Also professor Daniel Reynolds provided me with timely and insightful guidance. Finally, and definitely the most important person in my life, I must thank my wife Suzanne. I never would have finished if it were not for my wife's support and assistance.

Kenneth R. Norton

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Abstract

The relationship between the size of the United States Air Force Space Command's lost satellite lists and thirteen other variables is investigated. The thirteen variables contain the Space Surveillance Center crew's effort to work the lost list, solar activity, geomagnetic field strength, and the number of observations received each day from seven space track sensors. To identify the relationship of cause and effect between the lost lists and the thirteen variables, simple and multiple linear regressions are used on a data set that begins on 1 January 1988 and ends on 31 December 1988. Multiple linear regression and basic time-series smoothing techniques are used to forecast the number of lost satellites.

The results of this study show that solar activity causes near earth satellites to "go lost". This study also shows that not all sensors respond to increases in the size of lost lists in the same manner. Finally, the best forecast for the size of the lost satellite lists is provided by a multiple linear regression.

A CORRELATION AND FORECASTING  
ANALYSIS ON LOST SATELLITES

I. Introduction

Background

Out of the earth orbiting population of approximately 8,000 satellites, 6,880 are near-earth. Out of this number, an average of 50 to 75 are on the United States Space Command's (USSPACECOM) Space Surveillance Center's (SSC) near earth lost satellite list, or "lost list". This lost list, which can grow up to ten times this number in just 3 to 4 days, alarms USSPACECOM command authorities, who see the size of the lost list as evidence that the SSC's surveillance of space is incomplete. Without a complete picture of the space environment, SSC's products such as satellite decay predictions and shuttle-satellite collision information cannot be made with absolute certainty. Finding a solution to the lost list problem would greatly improve the accuracy of the satellite database information, which in turn would improve these and other products that the SSC generates.

The lost list contains all man-made satellites which have a period less than 2.5 minutes, have been cataloged by

the SSC, and have had no sensor observations that correlate closely to their mathematical model for two or more days. The lost list is one of many outputs the SSC produces each day to accomplish its mission.

The SSC mission is to detect, track, identify, and maintain surveillance on all man-made objects in earth orbit through tasking requirements levied on a network of world wide sensors. The SSC maintains an accurate database catalog of all of these space objects and provides orbital data on them to military, civilian, and scientific agencies (3:1-11). The Space Surveillance Center (SSC), located in Cheyenne Mountain in Colorado Springs, Colorado performs the space surveillance portion of USSPACECOM's national defense mission (3:1-10).

USSPACECOM's mission is to provide an integrated command structure, comprised of the four military services, for conducting satellite tracking, satellite control and satellite launch operations. It is also responsible for providing integrated warning and assessment of attacks on the Continental U.S. by ballistic missiles, bombers, cruise missiles and space related threats. USSPACECOM provides the North American Aerospace Defense Command (NORAD) with the capability for both warning and assessment of all aerospace attacks on North America.

To accomplish its tracking mission, the SSC uses mathematical models to predict a satellite's position. These

models are updated periodically. This is necessary because a satellite's orbit is constantly changing, resulting in a deviation between the true path of the satellite and its predicted orbital path. The SSC updates its predictions, using the observations from sensors, and distributes these predictions back to the Space Sensor Network (SSN). The sensors then update their data files so that they may continue to track space objects (See Figure 1).

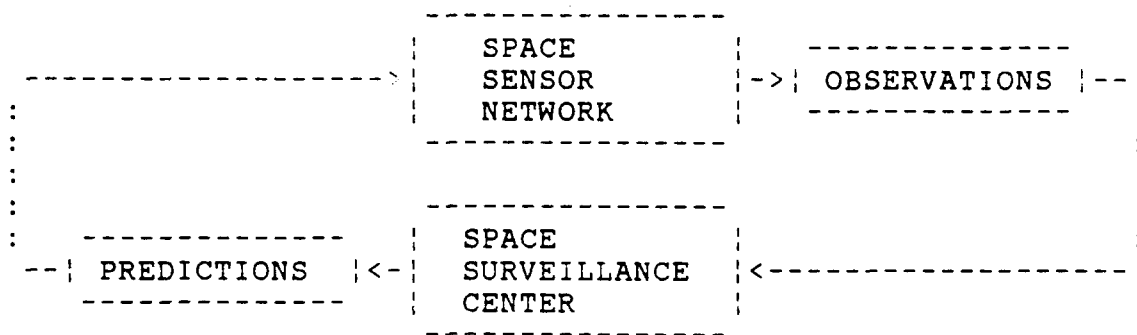


Figure 1. The Space Surveillance Loop

The surveillance of space requires that observations be taken at least every two days on every satellite by an SSN comprised of only twenty five sensors. To do this the SSC uses a process called selective tasking. Selective tasking involves setting each sensor's observation requirements for every satellite in order to meet SSC tasking goals. The lost list exists because the SSC has failed to meet these tasking goals.

The SSC has three tasking goals. They are: to obtain the proper number and dispersion of observations on each

satellite, to ensure the most efficient use of the SSN, and to have observations on high interest satellites forwarded on a priority basis. These goals ensure the SSC will get a sufficient number of observations for all satellites. They also ensure that the number of observations received on a satellite are the proper amount given its mission and orbital parameters. Finally, these goals ensure that the observations are spread out over as much of a satellite's orbit as possible rather than clustered in one area.

#### Research Objective

The purpose of this research project is to test a hypothesis concerning why satellites "go lost" and to forecast the number of lost satellites. The hypothesis is that the lost list rises because of an increase in solar or geomagnetic activity or because of a decrease in the number of observations sent in by sensors or some combination of these factors. To do this, the research project attempts to find a correlation between the number of lost satellites and the following: crew activity, solar activity, geomagnetic field strength, and number of daily sensor observations sent in from seven sensors to the SSC. These correlations, are examined to determine cause and effect relationships.

The data are the result of space surveillance activity conducted in 1988. First the data variables are analyzed and explained. Then various mathematical techniques are

used until either a satisfactory correlation or forecast is found, or until a conclusion that no correlation or satisfactory forecast model exists.

### Overview

The remainder of this study includes a literature review of solar phenomena and geomagnetic interactions with satellites (Chapter II), data collection and description (Chapter III), methodology used to analyze the problem (Chapter IV), results of the analysis (Chapter V), and finally, conclusions and recommendations (Chapter VI).

## II. Review of Literature and Background Development

### Overview

The element set is fundamental to space surveillance operations. The Space Surveillance Center uses the element set to mathematically model each and every satellite's position. Each element set is comprised of six parameters which uniquely define the orbit. The element set needs to be updated periodically because a satellite's orbit is changing due to perturbations. The effects of these perturbations, which are related to solar activity, change the satellite's path through space. If this change is too sudden, sensors will either no longer be able to track the satellite or will track, but not identify, the satellite.

In this chapter three topics pertinent to this thesis are reviewed. The specific topics discussed are orbital mechanics, perturbative forces that act on a satellite's orbit, and the space sensor network.

### Orbital Mechanics

Concepts and definitions of orbital mechanics necessary to understand a satellite's orbital motion about the earth are reviewed here. To completely describe each orbit, a set of parameters which uniquely defines the orbit is used. The purpose of these parameters is to discriminate one satellite from the thousands of satellites in orbit. Each unique set

of parameters is called an "orbital element set". These five independent quantities called "orbital elements" are sufficient to completely describe the size, shape and orientation of a satellite's orbit. A sixth element is required to pinpoint the position of the satellite along the orbit at a particular time (1:58).

The six quantities necessary to form an element set are: right ascension of the ascending node, inclination, semi-major axis, eccentricity, argument of perigee, and time of perigee passage. Together they constitute a set of orbital elements known as a Keplerian element set (4:2-29). According to the Orbital Analyst Handbook, the Space Surveillance Center uses two quantities from the Keplerian element set to locate the orbital plane in space, two quantities to describe the size and shape of the orbit, one quantity to orient the orbit within the orbital plane, and the last quantity to locate the satellite within the orbit (3:2-5). See Figure 2.

Right ascension of the ascending node and inclination locate the orbital plane in space. Right ascension of the ascending node is an angular measurement made along the equatorial plane. The right ascension measurement starts at the vernal equinox and progresses eastward to the orbit's ascending node. The vernal equinox is the imaginary line passing from the center of the earth, through the equator, to the first point of Aries at the instant winter changes to

spring. This is shown in Figure 3. The ascending node is defined as the point at which the satellite's ground trace intersects the equator as the satellite travels from the southern hemisphere into the northern hemisphere. Inclination is an angular measurement made at the ascending node. It is the angle between the equatorial plane and the orbital plane. Inclination is measured in a counterclockwise direction.

The semi-major axis describes the size of the satellite's orbit, while eccentricity describes the orbit's shape. For a near earth orbiting satellite, its orbital shape can only be circular or elliptical. The semi-major axis is one-half the longest diameter of the orbit. The longer the semi-major axis, the larger the orbit. The semi-major axis is useful to determine the period of an orbit. The period is simply the amount of time it takes the satellite to complete one orbit.

The argument of perigee orients the orbit within the orbital plane. It is an angular displacement along the orbital path, from the ascending node to perigee, measured in the direction of the satellite's motion.

Time of perigee passage locates the satellite in the orbit by specifying the last time the satellite was at its perigee. Perigee is the point in the satellite's orbit that is closest to the earth.

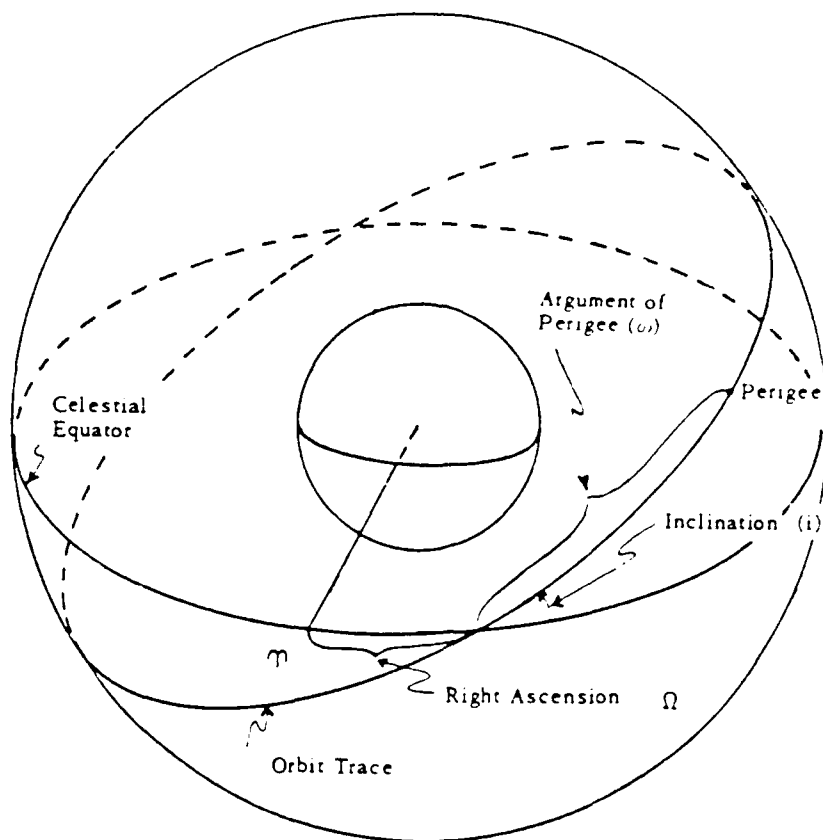
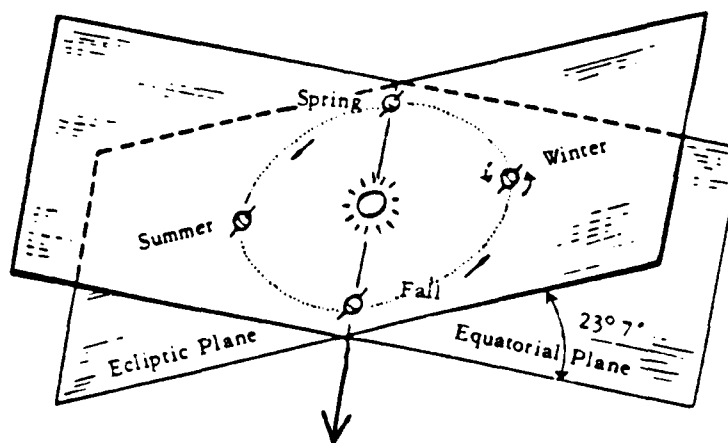


Figure 2. Orbital Elements (4:28)



TO THE FIRST  
POINT OF ARIES ( $\Upsilon$ )

Figure 3. The Vernal Equinox (4:28)

## Perturbations

A satellite's orbit is constantly changing over time because outside forces are acting upon it. The true path of the satellite will deviate from its element set's predicted orbital path because of these forces. The Space Handbook states,

These outside forces, known as perturbations, cause deviations in the orbit from those predicted by two-body orbital mechanics. (4:2-41)

The major perturbative forces at work on satellites in near earth space are atmospheric drag, electromagnetic drag and radiation pressure. Near earth is the region above the earth's surface where a satellite's orbital period is between 87.5 minutes and 225 minutes. The near earth space environment has a higher particle density, less electromagnetic energy, and more satellites than the deep space environment.

Atmospheric drag is friction between the earth's upper atmosphere and the satellite. This drag force not only changes a satellite's orbit, but also causes the satellite to decay back to earth. Solar activity causes the upper atmosphere to expand, increasing drag. The last time "solar max" occurred, the Earth's upper atmosphere expanded enough, through the warming of ultraviolet radiation, to send 85 tons of Skylab satellite to a premature end (9:92). Solar Max occurs at the point where the highest solar activity values are recorded during the eleven year solar cycle. The

second major perturbative force is radiation pressure, which is the pressure exerted on a satellite by the solar wind. The solar wind is the ever present flow of particles and ionized gases streaming outward from the sun. The particles in the solar wind stream pass the earth with velocities ranging from 400-800 km/sec on the average. Extremely large solar disturbances can result in solar wind velocities in excess of 2,300 km/sec. Consequently, radiative pressure from the sun is a major source of perturbation for satellites with large area to mass ratios (3:6-5).

Grover describes the correlation between solar activity and geosynchronous satellite orbits. He states that solar activity that is two or more standard deviations above normal will cause a substantial increase in radiation pressure. The result of this rise is anomalies in a satellite's orbit (7).

The electromagnetic perturbation on a satellite results from the satellite's motion through the Earth's magnetic field. The field produces an electromagnetic force which tries to make the satellite align itself with the magnetic field. There are two phenomena which cause the earth's magnetic field to interact with the satellite. The first is the satellite's electrical/electronic equipment sets up a magnetic field of its own. The second is the ionized gases that the satellite passes through cause electrical charges to build up on the satellite's skin (3:6-5). Grover sug-

gests that solar activity affects the earth's magnetic field that contains all earth orbiting satellite's. He postulates that solar activity releases photons which strike molecules in the earth's upper atmosphere, liberating high energy electrons (6:64). The release of these high energy electrons strengthen the magnetic field, creating more electromagnetic drag.

Solar activity is closely related to all three of these perturbative forces. However, the relationship is not well understood (4:1-7). This uncertainty and the approach of solar max in 1991, causes physicists to again struggle with the uncertain art of solar activity forecasting in an attempt to forestall problems with other satellites (9:902).

To predict the effects of solar activity on an orbit, the Space Surveillance Center uses two solar-geophysical values, AP and F10 values, gathered by the National Oceanic and Atmospheric Administration in Boulder, Colorado. The AP value is a daily index of geomagnetic activity. It represents the degree to which the geomagnetic field varies. According to a Solar-Geophysical report, AP is an indicator of short-term changes in the earth's upper atmosphere (2:31). The F10 value is a daily solar activity observation measured at Ottawa, Canada. The F10 value rises rapidly during solar outbursts, usually optical flares. It is a good indicator of changes in solar output which cause variations in the earth's upper atmosphere. Consequently, it is

frequently used as a SSC satellite modeling input to predict long-term changes in atmospheric drag (2:10). The value of these quantities categorize solar activity as being either in a quiet, unsettled, active, minor storm, major storm, or severe storm state (12:3).

#### Space Sensor Network

The mission of the Space Sensor Network is to maintain surveillance on all earth orbiting satellites, and to detect newly launched foreign satellites. Of the 25 sensors in the Space Sensor Network, 17 are capable of tracking near-earth satellites (3:3-4 thru 3-6).

The Space Surveillance Center utilizes the Space Sensor Network resources by tasking the sensors to take positional (metric observational) data on satellites as they pass through the sensor's coverage. The metric observations give the exact position of the satellite in relation to the radar location.

Sensors are divided up into three categories: dedicated, contributing, and collateral. A dedicated sensor is a USSPACECOM operationally controlled sensor with a primary mission of spacetrack support. A contributing sensor is a non-USSPACECOM sensor under contract by the Air Force to provide spacetrack support as requested by USSPACECOM. A collateral sensor is a USSPACECOM operationally controlled sensor that provides spacetrack support, but with a primary

mission of something other than spacetrack (3:3-4). Contributing and collateral sensors provide only limited support. The collateral sensors have a primary mission of missile warning or intelligence gathering which limits spacetrack time. The contributing sensors have contract limitations which keep them from spacetracking at certain times or under certain conditions. The number of observations a sensor takes is related to it being dedicated, collateral, or contributing (11).

Phased array sensors, because of their accuracy, sensitivity, and capacity, provide more observations than mechanical trackers. Phased arrays can track multiple targets (satellites), which account for their large number of observations relative to mechanical trackers (11).

Morris believes that two sensors, the Eglin and PARCS phased arrays, contribute most of the observations needed to keep the lost list at its "normal level". This is because they are the two most sensitive sensors in the SSN. They can track satellites that other sensors simply cannot "see" (11).

Finally, KAMAN Sciences', a government contractor providing engineering and software support to the SSC, studies show that EGLIN and PARCS contribute over 31% of the total observations received daily in the Space Surveillance Center (8). If these two sensors are down for more than a day, the number of lost satellites increases. In 1989, during a four

day period of high solar activity, the 2 day lost list or "attention list" soared from its normal level of about 120 lost satellites to over 1200. This is believed to be partially the result of Eglin and PARCS being unavailable during some of this period (11). Any study of the lost list must contain these two sites.

### III. Data Collection and Description

#### Data Collection

The sensor data used in this study was obtained from the Space Surveillance Center's database. KAMAN Sciences is the civilian contractor responsible for maintaining and upgrading software used in the SSC's Honeywell mainframe computer. The contractor uses a program named ANASAR to capture data from the computer system. The program ANASAR was written by Ford Aerospace, the original software support contractor, in 1979 when the current SSC computer system became operational. The program captures data ranging from the number of observations received from all the sensors to the number of satellites currently cataloged by the SSC. This data is kept by the company until it is briefed to USSPACECOM. The data was available through KAMAN Sciences on floppy disks, tapes and hard copy reports. It took months to find the people at KAMAN who kept the data. Data was collected over a fifteen month period with the last set arriving in September of 1990. The importance of data preparation to this study can not be overstated.

Both the data entry and verification are an important part of the data preparation process. Approximately 7,000 values needed to be assimilated and verified. The data is first converted and assimilated into an ASCII II data file in the form of a 17 by 366 matrix. Then the values are

verified with hard copy printouts before use in the available mathematical processing software.

This data set is selected for two reasons. The first is that it is readily available to the SSC's operational crews. There are, for example, other indices which could be used as an indicator of solar and geomagnetic activity. However, since the SSC does not use them in its modeling techniques they are not incorporated into this study. Also, if a good predictor model can be created it must use inputs that are available to the SSC crews. A predictor model is needed so that crews can make more informed decisions about such things as whether to delay a key sensor's preventive maintenance down time, bring in more analysts or delay other computer processing jobs in an effort to keep the number of lost satellites down.

The second reason is that, based upon conversations with experienced Space Command personnel, this data set is a good sample of what accurately affects the lost list.

The daily data captured by KAMAN Sciences and used in this thesis spans 366 days starting on 1 January 1988 and ending on 31 December 1988. One day's worth of data consists of 17 fields. Four of these fields are the number of 2 day, 3 day, 4 day and more than 4 day lost satellites. Two fields refer to the SSC's Application Program 515 (AP515). Two fields are solar activity values, two are geomagnetic activity values and the remaining fields are

number of observations (obs) received from seven sensors. Those sensors are Eglin, PARCS, NAVSPASUR, Otis, Beale, Robins and Eldorado. All the data used in this study is shown in Appendix A.

TABLE 1  
FIELD DESCRIPTIONS

| FIELD      | DESCRIPTION                                      |
|------------|--------------------------------------------------|
| : LOST 2   | :NUMBER OF SATELLITES LOST TWO DAYS :            |
| : LOST 3   | :NUMBER OF SATELLITES LOST THREE DAYS :          |
| : LOST 4   | :NUMBER OF SATELLITES LOST FOUR DAYS :           |
| : LOST 5   | :NUMBER OF SATELLITES LOST FIVE OR MORE DAYS :   |
| : AP LOADS | :NUMBER OF TIMES AP515 RAN :                     |
| : AP CPU   | :DURATION OF AP515 RUN TIME IN COMPUTER SYSTEM : |
| : F10 BAR  | :SOLAR ACTIVITY VALUE :                          |
| : F10 ACT  | :SOLAR ACTIVITY VALUE :                          |
| : AP MAX   | :GEOMAGNETIC ACTIVITY VALUE :                    |
| : AP AVG   | :GEOMAGNETIC ACTIVITY VALUE :                    |
| : EGL      | :NUMBER OF OBS FROM THE SENSOR EGLIN :           |
| : PAR      | :NUMBER OF OBS FROM THE SENSOR PARCS :           |
| : NAV      | :NUMBER OF OBS FROM THE SENSOR NAVSPASUR :       |
| : OTS      | :NUMBER OF OBS FROM THE SENSOR OTIS :            |
| : BLE      | :NUMBER OF OBS FROM THE SENSOR BEALE :           |
| : RBN      | :NUMBER OF OBS FROM THE SENSOR ROBINS :          |
| : ELD      | :NUMBER OF OBS FROM THE SENSOR ELDORADO :        |

#### Data Description

LOST SATELLITES, AP, AND F10. The LOST variable used in this study represents the number of near-earth satellites lost in a specified category that day. The LOST 2 variable refers to the number of satellites lost for 2 days, LOST 3 refers to number of satellites lost for 3 days, and LOST 4 is the number of satellites that have been lost for 4 days. The LOST 5 is different because it contains not only the

number of satellites lost for 5 days, but also satellites lost for more than 5 days.

The LOST 2 and LOST 5 variables are used as the dependent variables throughout this study. These satellites are near-earth satellites cataloged by the SSC that are without observations that fully correlate to the predicted element set position within a specified time period. These numbers do not include deep space lost satellites. The category of deep space lost satellites represent different cause and effect factors which is not relevant to this study.

The AP LOADS variable refers to the number of times the program ASSOC is run in the SSC each day, while AP CPU is the total amount of time, in seconds, that the program ran that day. This program is used by the analysts to conduct a SSC database search for observations that may fully correlate to a lost satellite. These fields indirectly represent the effort orbital analysts are putting into "finding" lost satellites. If an observation is found and it is not older than two days, it updates the element set. The satellite is then removed from the lost list. This program is on the SSC's lost list checklist. This checklist is executed three times a day as time permits.

The F10 ACT value is an average of the daily solar activity observation which is measured in Ottawa, Canada in units of 10-22 watts/meter. They are sent each day from the Solar observatory in Boulder, Colorado. The F10 BAR is a an

average of the previous 90 day's worth of daily F10 ACT values. F10 values rise rapidly during solar bursts, usually optical flares. They are both good indicators of changes in the solar output which cause variations in the earth's upper atmosphere. Consequently, it is frequently used as an input to predict long term changes in atmospheric drag (2:10). The daily values follow both the 28 day and 11 year solar cycles and are associated with all observed optical flares. The SSC uses these values as an input parameter to atmospheric density models to gauge changes. These atmospheric density models are used by other programs which update a satellite's element set.

The AP values are daily indices of geomagnetic activity and are also sent to the SSC from the Solar observatory. The APAVG represents the daily average while the AP Max is the maximum recorded value for that day. They represent the degree to which the geomagnetic field strength varies. According to a Solar-Geophysical report, AP has been found to be an indicator of short-term changes in the earth's upper atmosphere (2:31). The SSC receives these values daily, from the Boulder observatory, as an input to its upper atmosphere density and satellite drag models. The following is a table showing the geomagnetic condition for various values of AP.

TABLE 2  
GEOMAGNETIC FIELD CONDITIONS (12:3)

| <u>AP VALUE</u> | <u>CONDITION</u> |
|-----------------|------------------|
| 0 - 7           | Quiet            |
| 8 - 15          | Unsettled        |
| 16 - 29         | Active           |
| 30 - 49         | Minor storm      |
| 50 - 99         | Major storm      |
| 100<=           | Severe storm     |

The values of AP used in this study are in the active condition category and represented to the SSC as the normally expected values.

SENSOR OBSERVATIONS. The space sensor network takes positional metric data or "observations" on satellites as they pass through the sensor's coverage. These daily observations give the exact position of the satellite in relation to the radar's location. The observations used in this study include all satellite category classes, all observation Association STATuses (ASTATs) and all observation types.

The SSC uses a classification system called "category classes" to prioritize satellites for the SSN to track. Through this system of categories the SSC is able to accom-

plish its tasking goal of using limited sensor resources to keep track of a large satellite population.

The phased array radars used in this study have three satellite categories. The lost list is made up of what the SSC categorizes as class 3 satellites. These satellites have the lowest tracking priority in near earth space. Categories (CATs) refer to the satellite's importance and resolve conflicts when two or more satellites are in a sensor's coverage at the same time and the phased array cannot track them all. Cat 1 objects are events of highest priority. Examples are new foreign launches, satellites in final stages of decay, and near earth maneuvers. Cat 2 objects are special events of high priority. Examples are deep space maneuvers, deorbits, domestic launches, special tests and projects, certain satellites in final stages of decay and SSC crew monitored satellites. Cat 3 are routine near earth satellites.

An ASTAT correlation refers to an observation's degree of association with an element set in the SSC's satellite catalog file (SATF). A sensor's observation is classified as ASTAT 1 when the observation fully associates to the position predicted by an element set in the SATF in plane, time and height. A sensor's observation is classified as ASTAT 2 when it only partially correlates to the satellite's position as predicted by an element set. ASTAT 3 or ASTAT 4

observations associate poorly or do not associate at all with any satellite's predicted position.

An "observation type" is based on how much positional data the observation provides on the satellite. Most of the observations used in this study were observation types 2, 3, or 4. These different observation types are all included as one number; the total number of daily observations sent in to the SSC from each sensor.

TABLE 3  
OBSERVATION TYPES

| <u>OB TYPE</u> | <u>OB TYPE CONTAINS</u>                                                                              |
|----------------|------------------------------------------------------------------------------------------------------|
| 0              | Time, Range Rate                                                                                     |
| 1              | Time, Elevation, Azimuth                                                                             |
| 2              | Time, Elevation, Azimuth, Range                                                                      |
| 3              | Time, Elevation, Azimuth, Range,<br>Range Rate                                                       |
| 4              | Time, Elevation, Azimuth, Range,<br>Range Rate, Elevation Rate,<br>Azimuth Rate, Range Acceleration. |
| 5              | Time, Right Ascension, Declination.                                                                  |
| 6              | Time, $\dot{X}$ , $\dot{Y}$ , $\dot{Z}$ , $\ddot{X}$ , $\ddot{Y}$ , $\ddot{Z}$                       |

Table 3 shows the 7 sensors whose observations were used in this study.

TABLE 4  
SPACE SENSOR SUMMARY

| NAME      | DATA LABEL | CATEGORY   | TYPE         | TRACKS  |
|-----------|------------|------------|--------------|---------|
| EGLIN     | EGL        | DEDICATED  | PHASED ARRAY | DS & NE |
| PARCS     | PAR        | COLLATERAL | PHASED ARRAY | NE      |
| NAVSPASUR | NAV        | DEDICATED  | CONTINUOUS   | NE      |
| OTIS      | OTS        | COLLATERAL | PHASED ARRAY | NE      |
| BEALE     | BLE        | COLLATERAL | PHASED ARRAY | NE      |
| ROBINS    | ROB        | COLLATERAL | PHASED ARRAY | NE      |
| ELDORADO  | ELD        | COLLATERAL | PHASED ARRAY | NE      |

NE = Near Earth  
DS = Deep Space

The EGL data represents the number of observations received by the SSC each day from the Eglin space track sensor. Eglin is a dedicated space track radar located in Florida's panhandle. Its exact location is 31 degrees north latitude, 274 degrees east longitude. It is a phased array sensor which can track multiple satellites at the same time. This tracker has one notable difference from the rest of the sensors used in this study. It is the only sensor that tracks both near earth and deep space objects on a regular basis.

The PAR data represents the number of observations received by the SSC each day from the Perimeter Acquisition Radar Characteristic System (PARCS) missile track sensor. PARCS is a collateral space track sensor with a primary mission of missile detection of sea launched ballistic missiles launched from the Hudson Bay. It is located in

North Dakota at 49 degrees north latitude, 262 degrees east longitude. It is a phased array sensor originally designed as part of this country's anti-ballistic missile system. Consequently it can simultaneously track very small objects.

The NAV data is the number of observations received from the SSC each day from the NAVal SPACe SURveillance center (NAVSPASUR) space track sensor. NAVSPASUR is a dedicated space track sensor using continuous array technology. It tracks any object crossing the 33rd latitude over the United States by using a system of five transmitters and three receivers. The metric information is then transmitted to the main site in Virginia for satellite correlation checks and then forwarded to the SSC.

The OTS data is the number of observations received by the SSC from the missile track sensor at Otis AFB on Cape Cod in Massachusetts. Otis is a collateral space track sensor with a primary mission of missile detection of sea launched ballistic missiles launched from the Atlantic Ocean. Its exact location is 24 degrees north latitude, 290 degrees east longitude. It is a phased array built in the 1970s which can simultaneously track multiple targets.

The BLE data is the number of observations received by the SSC from the Beale missile track sensor in California. Beale is a collateral space track sensor with a primary mission of missile detection of sea launched ballistic missiles launched from the Pacific Ocean. Its exact loca-

tion is 39 degrees north latitude, 239 degrees east longitude. It is a phased array built in the 1970s which can simultaneously track multiple targets. The RBN data is the number of observations received by the SSC from the Robins missile track sensor in Georgia. Robins is a collateral space track sensor with a primary mission of missile detection of sea launched ballistic missiles launched from the Gulf of Mexico and the Atlantic Ocean. Its exact location is 30 degrees north latitude, 276 east longitude. It is a phased array built in the late 80s which can simultaneously track multiple targets.

The ELD data is the number of daily observations received by the SSC from Eldorado the missile track sensor in Texas. Eldorado is a collateral space track sensor with a primary mission of missile detection of sea launched ballistic missiles launched from the Gulf of Mexico and the Pacific Ocean. Its exact location is 30 degrees north latitude, 260 degrees east longitude. It is a phased array built in the late 80s which can simultaneously track multiple targets.

These 7 sensors out of a Space Sensor Network of 25 sensors are the only sensors used in this study. Their cumulative daily observation input represents over 80% of near earth observations received by the SSC (11).

The remaining sensors were omitted for various reasons. Some sensor sites, for example Millstone run by MIT in

Massachusetts, were left out because they tracked only deep space objects. Other sites, such as Altair in the Pacific, only tracked near earth category class 1 or 2 objects which do not make up the lost list.

Finally, any sensors that tracked only a small portion of the total near earth satellite population were left out. Shemya, a phased array sensor, located at 53 degrees north longitude, 174 degrees east latitude in the Aleutian Islands was omitted. This sensor's high longitude location prevents all low inclination satellites from being visible.

#### IV. METHODOLOGY

##### STEP 1

The first step in the analysis is to identify a strong 1 to 1 relationship between the number of lost satellites and each of the independent variables. The goal is to identify significant correlations in an attempt to identify independent variables which may cause the lost lists to change. The reverse is also of interest: independent variables which change as a result of changes in the lost lists.

Simple regression is used to fit the data to three functional relationships. The first relationship is linear and has the following form.

$$Y = a + bX \quad (1)$$

The second relationship is an exponential. Its form is:

$$Y = e^{a + bX} \quad (2)$$

The final functional form is multiplicative in the following format:

$$Y = aX^b \quad (3)$$

The best correlation coefficients of the simple regression correlation analysis between the number of lost satellites and each of the independent variables are used to understand lost list causation. The results of the regres-

sion are in two statistical measures; R, the correlation coefficient and an F-ratio test for significance of the correlation coefficient.

R is a parameter which measures the strength of the relationship between two sample variables (4:484). R-values range from -1 to +1. A -1 indicates a perfect linear fit with one variable decreasing while the other increases. A +1 indicates a perfect fit, with this fit having both variables either falling or rising together. R-values between -1 and +1 show a lesser degree of correlation with zero indicating no relationship.

The F-ratio determines if the results of the regression analysis are significant or due to random effects (10:155). The F-test indicates from a statistical point of view whether to use the mean or a regression relationship to describe the data. The F-test results will be shown as an "F-test Sig. Level" in the results. The correlation coefficient is significant to one minus this "F-test Sig. Level" value. The F-test Significance level used here was .10 or a 90% confidence level.

## STEP 2

Multiple linear regression is used to create two combined models for the two day lost list and then two for the five day lost list. In the first combined model, the multiple regression is used to determine the combined causalational

effects of the independent variables. In the second combined model, the multiple regression forecasts the size of the lost list.

In each multiple linear regression a Durbin Watson (DW) value, Degrees of Freedom (DF) value, Mean Squared Error (MSE), Mean Absolute Percentage Error (MAPE) and an R-Squared value are assessed. The DW value indicates if there is autocorrelation among the residuals. The MSE value is a measure of accuracy computed by squaring the individual error for each item in the data set and then finding the average or mean value of the sum of those squares (10:689). The MSE calculation is (10:569):

$$MSE = \frac{\sum_{i=1}^N (X_i - F_i)^2}{N} \quad (4)$$

where

$X_i$  is the actual value

$F_i$  is the forecast

$N$  is the number of data values

The MAPE calculation is (10:570):

$$MAPE = \frac{\sum_{i=1}^N \text{abs}((X_i - F_i) * 100 / X_i)}{N} \quad (5)$$

where

$X_i$  is the actual value

$F_i$  is the forecast

N is the number of data values

abs is the absolute value of

The R-Squared is the ratio of explained variance to total variance. The R-Squared calculation is (10:183):

$$R\text{-Squared} = \frac{\sum_{i=1}^N (Y'_i - \bar{Y})^2}{\sum (Y_i - \bar{Y})^2} \quad (6)$$

where

$\bar{Y}$  is the mean of Y

$Y'_i$  is the estimated value

$Y_i$  is the actual value

N is the number of data values

To use these results the method must satisfy the four assumptions of linearity, independence of residuals, homoscedasticity, and normality of residuals.

The linearity assumption is that the relationship between the dependent variable and independent variables is some type of linear function. Since the objective is to see if a linear fit between the dependent variable and the independent variables exists, this will be tested.

Independence of residuals assumption states that there is no time dependency among successive residuals (10:206). The DW value is used to see if this condition is satisfied. If a dependency is found, it usually indicates that the model used a nonoptimal number of independent variables,

incorrect functional forms, or there are strong trends in the variables (10:206).

Multiple linear regression also assumes homoscedasticity. This is that the residual errors have the same variance over the entire range of data. This will be determined by looking at the percentage errors across all observations.

The final assumption is that the mean error terms have a normal distribution. The residuals in this study are the outcome of a large number of unimportant factors that influence the dependent variable only slightly. On the average their influence is canceled out (10:206). Because this study uses 366 days worth of data and if the other assumptions are met, then it is reasonable to assume residuals are normally distributed.

A F-test is conducted after a multiple linear model is developed and all assumptions are satisfied. This indicates whether a significant functional linear relationship exists between the dependent variable and the combined effects of the independent variables. The F-test is the ratio of the explained variance over the unexplained variance (10:185). It is tested at a confidence level of 95%. The F-test calculation is (10:160):

$$F = (r^2/(k-1))/((1-r^2)/(n-k)) \quad (7)$$

where

$r$  is the correlation coefficient

k is the number of variables

n is the number of observations

Next t-tests at a 95% confidence interval are used to determine the significance of individual coefficients of the regression equation. This test determines whether any of the coefficients are significantly different from zero. The test, when very significant, also indicates that no serious multicollinearity exists where some independent variables are highly correlated with each other. Multicollinearity could cause erroneous regression results in the form of misleading forecasts (10:209). The hypothesized multiple linear regression equation is (10:180):

$$Y = \beta_0 + \beta_1 * X_1 + \beta_2 * X_2 + \dots + \beta_n * X_n \quad (8)$$

where

Y is the value of the dependent variable

$\beta_0$  is the constant of the equation

$\beta_i$  is the  $i^{th}$  coefficient

$X_i$  is the value of the  $i^{th}$  independent variable

### STEP 3

There are two types of forecasting methods used in this study: explanatory/causal and time-series. Explanatory forecasting is done in the second half of step 2 with multiple linear regression. It assumes that there exists a cause and effect relationship between independent variables and

the dependent variable. Through this relationship, changes in the independent variables affect the number of lost satellites in a predictable way. The extent of this change can be used to predict the future size of the lost list. Time-series is different from causal modeling in that it treats the system as a black box and makes no attempt to discover the factors affecting its behavior (10:15).

Time-series forecasting does not require understanding how the system operates or why changes occur. The use of a particular time-series technique assumes underlying stochastic patterns in the data such as stationarity, trend and seasonality. A data set whose mean and autocovariance structure does not depend on time is considered stationary. Trend data exhibits an increasing or decreasing behavior in the long-run. Seasonality refers to periodic patterns of the data.

In this final step, a basic time-series model will be proposed for satellites on the two and five day lost lists. The following four time-series smoothing techniques are investigated on four data sets; exponential smoothing, adaptive response rate single exponential smoothing, Holt's two parameter smoothing and Winter's seasonal smoothing. Two "model" data sets, one each for the two lost lists, will use the number of lost satellites from 5 February 1988 to 15 June 15 1988. This model data set contains 133 data points and is used to develop a time series model with each of the

four methods. Two "test" data sets, one for each lost list, use the number of lost satellites from 11 July 1988 to 11 October 1988. This test set contains 93 data points and is used to check for consistency of results with the model set.

The first time-series method used is exponential smoothing. It uses a parameter, alpha ( $\alpha$ ), for weighting of both the most recent data point and the last forecasted point. This method is appropriate when there is no trend or seasonality in the data. The forecasting equation is (10:49):

$$F[t+1] = \alpha * X[t] + (1-\alpha) * F[t] \quad (9)$$

where

$F[t+1]$  is the next forecast

$\alpha$  is the inputted value between 0 and 1

$X[t]$  is the most recent data point

$F[t]$  is the last forecast

A high value of alpha weighs the most recent data point more than the last forecasted point, while a low value of  $\alpha$  lowers its impact on the next forecast. It can be easily seen by substituting  $F[t]$  in the above equation with  $F[t] = \alpha * X[t-1] + (1-\alpha) * F[t-1]$  that the impact of past data on the forecast decreases exponentially. The best alpha for the lost lists is obtained through trial and error using .01 increments.

Adaptive Response Rate Single Exponential Smoothing

(ARRSES) is different from exponential smoothing in that this method changes the alpha at each successive time lag. This is to respond to changes in the data pattern which make the initial alpha no longer appropriate. ARRSES also assumes that there is no trend or seasonality in the data. Alpha is set by the following equations (10:54):

$$F[t+1] = \alpha[t]*X[t] + (1-\alpha[t])*F[t] \quad (10)$$

where

$$\alpha[t+1] = \text{abs}((E[t])/(U[t])) \quad (11)$$

$$E[t] = b*(X[t]-F[t]) + (1-b)*E[t-1] \quad (12)$$

$$U[t] = b*(X[t]-F[t]) + (1-b)*U[t-1] \quad (13)$$

$X[t]$  is the most recent data point

$F[t]$  is the last forecast

abs is the absolute value of

b is smoothing constant set to 0.1

The third time-series is Holt's Two Parameter Smoothing and it assumes that the data has a linear trend but is otherwise stationary. This method uses two smoothing parameters, alpha ( $\alpha$ ) and beta ( $\beta$ ), to make its forecast. The best alpha and beta for each of the four data sets are obtained through trial and error using .01 increments. The forecasted value is calculated using the following equations (10:64):

$$F[t+1] = S[t] + D[t] \quad (14)$$

where

$$S[t] = \alpha * X[t] + (1-\alpha) * (S[t-1] + D[t-1]) \quad (15)$$

$$D[t] = \beta * (S[t] - S[t-1]) + (1-\beta) * D[t-1] \quad (16)$$

F[t+1] is the next forecast

S[t] is the smoothing of the data

D[t] is the smoothing of the trend

$\alpha$  is a smoothing parameter

$\beta$  is a smoothing parameter

The last time-series technique is Winter's seasonal smoothing. This technique assumes the data fluctuates because of stationarity, trend and seasonality. It uses three parameters to forecast, alpha ( $\alpha$ ), beta ( $\beta$ ), and gamma ( $\gamma$ ). The method is based on three equations, each of which smooths a parameter associated with one of the three components of pattern. Smoothing constants are between zero and one. The equations for a Winter's forecast are (10:72):

$$F[t+1] = (S[t] + D[t]) * I[t-s-1] \quad (17)$$

where

$$S[t] = \alpha * (X[t] / I[t-s]) + (1-\alpha) * (S[t-1] + D[t-1]) \quad (18)$$

$$D[t] = \beta * (S[t] - S[t-1]) + (1-\beta) * D[t-1] \quad (19)$$

$$I[t] = \gamma * (X[t] / S[t]) + (1-\gamma) * I[t-s] \quad (20)$$

F[t+1] is the next forecast

X[t] is the most recent data point

$S[t]$  is the stationarity at time  $t$   
 $D[t]$  is the trend at time  $t$   
 $I[t]$  is the seasonal index at time  $t$ .  
 $\alpha$  is a smoothing parameter  
 $\beta$  is a smoothing parameter  
 $\tau$  is a smoothing parameter

#### MODEL COMPARING

It is useful to use a different forecasting method called the Naive Forecast 1 (NF1) as a basis in evaluating other methods in a given data set. This method uses as a forecast the most recent information available in forecasting the actual value (10:570). It simply uses the number of lost satellites today as the prediction for the number of lost satellites tomorrow.

## V. Results of Analysis

### Simple Regression Causation Analysis

The results shown in Table 5 are from the best simple regression models fit with the 17 independent variables against both the two and five day lost variables, LOST 2 and LOST 5. All three model fits were tested, but in all cases, the best fit is obtained with a linear model as opposed to the exponential or multiplicative models.

TABLE 5  
ONE-TO-ONE LINEAR REGRESSION RESULTS  
OF THE 2 AND 5 DAY LOST LISTS

| INDEPENDENT<br>VARIABLE | 2 DAY<br>CORRELATION<br>COEFFICIENT | 2 DAY<br>F-TEST<br>SIG. LEVEL | 5 DAY<br>CORRELATION<br>COEFFICIENT | 5 DAY<br>F-TEST<br>SIG. LEVEL |
|-------------------------|-------------------------------------|-------------------------------|-------------------------------------|-------------------------------|
| : LOST 2                | : 1                                 | : .00000                      | : .356927                           | : .00000                      |
| : LOST 3                | : .524740                           | : .00000                      | : .417252                           | : .00000                      |
| : LOST 4                | : .375023                           | : .00000                      | : .463404                           | : .00000                      |
| : LOST 5                | : .356927                           | : .00000                      | : 1                                 | : .00000                      |
| : AP LOADS              | : .145691                           | : .00582                      | : .223495                           | : .00002                      |
| : AP CPU                | : -.067550                          | : .20291                      | : .016414                           | : .75727                      |
| : F10 BAR               | : .217645                           | : .00003                      | : .248148                           | : .00000                      |
| : F10 ACT               | : .229773                           | : .00001                      | : .274434                           | : .00000                      |
| : AP MAX                | : -.096120                          | : .06968                      | : -.030506                          | : .56563                      |
| : AP AVG                | : -.111751                          | : .03480                      | : -.061169                          | : .24900                      |
| : EGL                   | : .088532                           | : .09535                      | : .348468                           | : .00000                      |
| : PAR                   | : .003015                           | : .95480                      | : .130995                           | : .01338                      |
| : NAV                   | : .067486                           | : .20334                      | : .185268                           | : .00043                      |
| : OTS                   | : -.080404                          | : .12998                      | : -.009359                          | : .86031                      |
| : BLE                   | : .073319                           | : .16687                      | : -.027681                          | : .60217                      |
| : RBN                   | : -.090277                          | : .08853                      | : -.080115                          | : .13083                      |
| : ELD                   | : .094899                           | : .07332                      | : .178322                           | : .00071                      |

The first four rows of Table 5 show that the LOST varia-

bles highly correlated with each other. These correlations are as expected.

The other correlations in Table 5 do not necessarily imply causation. To properly analyze correlations for cause and effect relationship, the space surveillance process being examined must be kept in mind. In light of that process, these correlations show some interesting as well as surprising results.

The AP LOADS and AP CPU correlations give conflicting indications for the two day lost list. They both show a weak negative correlation with opposite results. The AP CPU correlation coefficient is not significant. The AP LOADS is significant and indicates that changes in the two day lost list are correlated with, and therefore may be attributed to crew activity. Results for the five day lost list are different. The AP LOADS and AP CPU correlations are positive, however only AP LOADS, is significant positive. It is irrational to believe that as the crews work more, the five day lost list rises. It is more likely that as the five day list rises, crew activity increases to control the number and reduce the lost satellite list.

The F10 ACT and F10 BAR solar index values have strong significant positive correlations with both lost lists. This indicates that as optical flares increase, the number of lost satellites increases in the LOST 2 and LOST 5 categories. This correlation is logical because solar activity

is known to affect satellite's orbits. The geomagnetic activity did not correlate very well with either the two or five day lost list. The correlations were all negative instead of the expected positive. Only the two day lost list geomagnetic correlations are significant. They indicate that the geomagnetic field strength does not affect a satellite's orbit enough to contribute to it "going lost". This is a surprising result since it was originally believed, through conversations with Space Command analysts, that this would be a factor in satellite's "going lost".

The analysis of the plots of dependent variables LOST 2 and LOST 5 versus the independent variable F10 ACT reveals some interesting points.

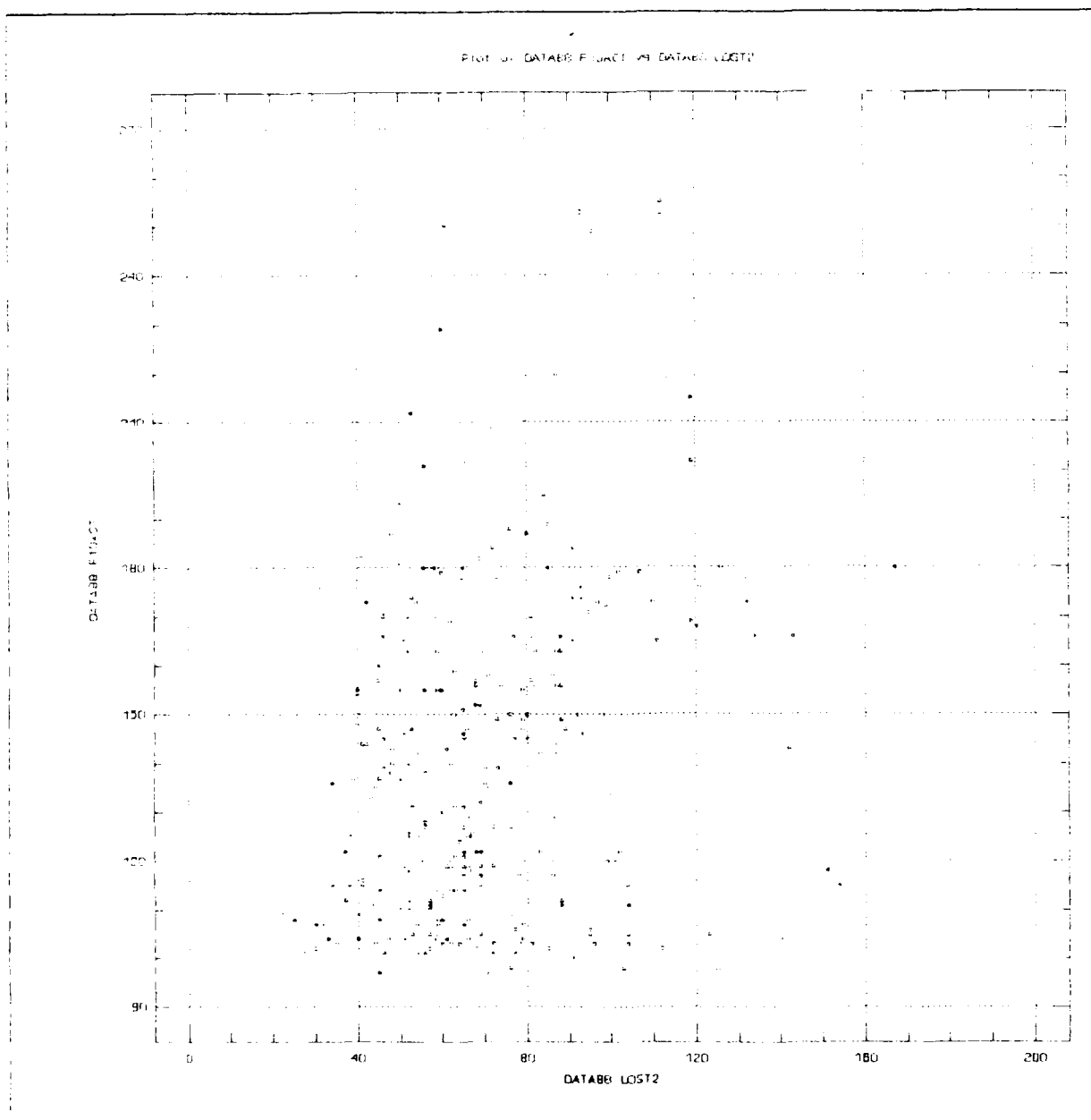


Figure 4. 2 Day VS F10 ACT

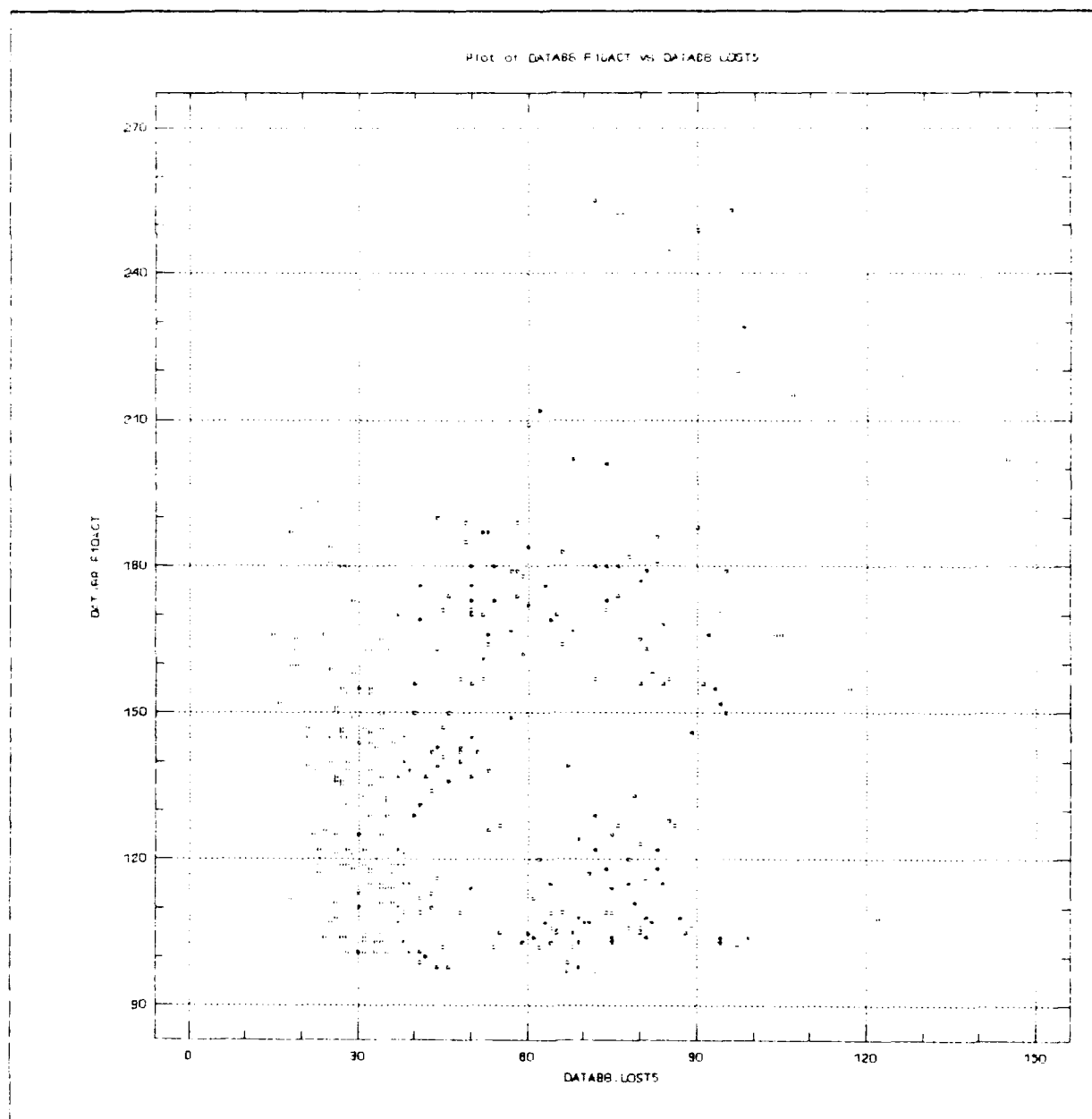


Figure 5. 5 Day VS F10 ACT

The two plots show a lack of points in the upper left and lower right corners. This lack of points in the opposite extremes indicate that low solar activity does not coincide with a high number of lost satellites or vice versa. The high density of points in the lower left and upper right corners of the plots show that low solar activity corresponds to a low number of lost satellites and that high solar events correspond to a high number of lost satellites. This trend indicates that solar activity does have some ability, though apparently small, to affect the two and five day lost lists. The middle lower portion of the plots where the lost lists increase without an increase in solar activity are perhaps increases caused by other variables.

The sensor correlation data showed both positive and negative correlations. The strongest correlations were on the five day list with Eglin, PARCS, NAVSPASUR, and Eldorado. All of these correlations were positive and significant. This indicates that as the five day list increases, these sensors are sending in more observations. On the two day list, the correlations were positive significant for Eglin and Eldorado, while negative significant for Robins. The variables are examined further by lagging.

Lagging the independent variables provides more information on causation between the dependent and independent variables. This procedure is useful in determining whether a lost list change triggers an independent variable change

or if a change in an independent variable causes the lost list to change. This lagging procedure would also be useful in identifying any time delays between changes in the lost lists in relation to each of the dependent variables.

An independent variable that has positive lag is using a past value to compare to the present lost list value. A negative lag uses a future value to compare against the present lost list number. All lag values are in days. Exponential and multiplicative models are attempted as well as a linear model to determine the best model fit. As before, the linear models are the best fit for the lagged values. The "best" lag factor is one which, using trial and error, produced the highest absolute correlation coefficient.

TABLE 6

ONE-TO-ONE LINEAR REGRESSION RESULTS  
OF THE 2 DAY LOST LIST WITH BEST LAG VALUES

| INDEPENDENT<br>VARIABLE | 2 DAY<br>CORRELATION<br>COEFFICIENT | BEST<br>LAG | F-TEST<br>SIG. LEVEL |
|-------------------------|-------------------------------------|-------------|----------------------|
| : LOST 3 :              | .718589 :                           | -1 :        | .00000 :             |
| : LOST 4 :              | .552985 :                           | -2 :        | .00000 :             |
| : LOST 5 :              | .446662 :                           | -3 :        | .00000 :             |
| : AP LOADS :            | .222735 :                           | -1 :        | .00002 :             |
| : AP CPU :              | .088172 :                           | -4 :        | .09862 :             |
| : F10 BAR :             | .221176 :                           | -3 :        | .00003 :             |
| : F10 ACT :             | .229773 :                           | 0 :         | .00001 :             |
| : AP MAX :              | -.137976 :                          | -1 :        | .00914 :             |
| : AP AVG :              | -.159977 :                          | -1 :        | .00247 :             |
| : EGL :                 | .221495 :                           | -4 :        | .00003 :             |
| : PAR :                 | .096515 :                           | -2 :        | .06972 :             |
| : NAV :                 | .097130 :                           | -2 :        | .06756 :             |
| : OTS :                 | -.080404 :                          | 0 :         | .12998 :             |

TABLE 6 (cont)

ONE-TO-ONE LINEAR REGRESSION RESULTS  
OF THE 2 DAY LOST WITH BEST LAG VALUES

| INDEPENDENT<br>VARIABLE | 2 DAY<br>CORRELATION<br>COEFFICIENT | BEST<br>LAG | F-TEST<br>SIG. LEVEL |
|-------------------------|-------------------------------------|-------------|----------------------|
| : BLE                   | : .073319                           | : 0         | : .16687             |
| : RBN                   | : -.090277                          | : 0         | : .08853             |
| : ELD                   | : .094899                           | : 0         | : .07332             |

The above correlations clarify the cause and effect relationship first shown in Table 5. The independent variables LOST are highly correlated with the two day lost list. These strong correlations identify a lag that shows a rise in the two day lost list today causing the greatest increase in the three day lost list tomorrow. It also causes an increase in the four day lost list two days from now, and an increase in the five day lost list three days from now.

The first four rows of Table 6 also approximately reflect the percentage of satellites on the two day lost list that end up on the other lost lists. About 72% of the two day lost satellites will not be found within the first day. These satellites will progress to the three day lost list. The table also shows that about 55% of the two day lost list will not be found within the first two days, and about 45% will not be found within three days.

The AP LOADS and AP CPU have strong significant positive correlations, one and four days, respectfully, after the two

day lost list increases. The correlation with the AP LOADS is strongest a negative one lag indicating that the crews work the lost list one day after it increases.

The F10 BAR and F10 ACT have strong significant positive correlations. The F10 BAR correlates highest three days after the two day lost list because it is a ninety day rolling average of F10 ACT daily values and so does not respond to F10 ACT changes quickly. The F10 ACT had zero lag indicating that optical flares have an immediate effect on the two day lost list.

The AP MAX and AP AVG negative significant correlations indicate that the geomagnetic field strength does not affect the two day lost list. If the geomagnetic field strength is a factor, it should have a positive, not negative, correlation.

The sensor correlations using the lag procedure show two important points. First, the two day lost list does not rise because of a decrease in observations from any sensor. If it did, it would have been expected to observe a negative correlation with a positive lag factor. Instead, the sensors have positive significant correlation with negative lags with three sensors: Eglin, PARCS and NAVSPASUR. The lags were -2 to -4 indicating that these sensors increased the number of observations they send in two to four days after the two day lost list increases. Comparing these results with Table 5, Eglin's correlation increased

from .008532 to .221495, PARCS from .003015 to .096515, and .067486 to .097130 from NAVSPASUR. The second discovery is that Otis, Beale, Eldorado and Robbins do not affect, and do not respond to, the two day list rising.

TABLE 7

ONE-TO-ONE LINEAR REGRESSION RESULTS  
OF 5 DAY LOST LIST WITH BEST LAG VALUES

| INDEPENDENT<br>VARIABLE | 5 DAY<br>CORRELATION<br>COEFFICIENT | BEST<br>LAG | F-TEST<br>SIG. LEVEL |
|-------------------------|-------------------------------------|-------------|----------------------|
| : LOST2                 | : .446662                           | : 3         | : .00000             |
| : LOST3                 | : .510975                           | : 2         | : .00000             |
| : LOST4                 | : .574658                           | : 1         | : .00000             |
| : AP LOADS              | : .271936                           | : -2        | : .00000             |
| : AP CPU                | : .142695                           | : -4        | : .00733             |
| : F10 BAR               | : .248148                           | : 0         | : .00000             |
| : F10 ACT               | : .277635                           | : -1        | : .00000             |
| : AP MAX                | : -.165492                          | : -11       | : .00201             |
| : AP AVG                | : -.16011                           | : 3         | : .00250             |
| : EGL                   | : .367112                           | : -1        | : .00000             |
| : PAR                   | : .152675                           | : -1        | : .00393             |
| : NAV                   | : .208379                           | : -1        | : .00007             |
| : OTS                   | : -.009359                          | : 0         | : .86031             |
| : BLE                   | : -.027681                          | : 0         | : .60217             |
| : RBN                   | : -.080115                          | : 0         | : .13083             |
| : ELD                   | : .196402                           | : -1        | : .00071             |

The correlations in Table 7 are between the five day lost list and each of the independent variables with the lag that resulted in the highest correlation coefficient. All the LOST independent variables highly correlated, as expected, with the five day lost list. The best lag factors found through trial and error made sense: for example, the present day five day lost list correlates best with the two day lost

list three days earlier. These strong correlations mean that a rise in the two day, three day, and four day lost lists "causes" the five day lost list to increase. This correlation was expected.

The first four rows of Table 7 show the percentage of satellites on the other lost satellite lists that end up on the lost five day list. The table shows that about 45% of the two day lost satellite list will stay lost for three more days, about 51% of the three day lost satellite list stay lost for two more days, and at least 57% percent of the four day lost satellites list will stay lost at least one more day.

The AP LOADS and AP CPU have their strongest significant positive correlation two and four days respectfully after the five day lost list increases. The correlation with the AP LOADS is strongest at a negative two lag indicating that the crews work the lost list two days more after it increases. The AP CPU's greatest increase is four days after the lost five day list increases. This is different than the results found on the two day lagged correlation analysis.

The F10 BAR and F10 ACT have strong significant positive correlations. The F10 BAR variable with no lag (same day) best correlates with the five day lost list. The F10 ACT had negative lag indicating that optical flares the day after have the greatest effect on the five day lost list.

Since the five day lost lists consists of satellites lost for five days or more, this negative lag is as expected.

The AP MAX and AP AVG have negative significant correlations, as with the two day lost list, indicating that the geomagnetic field strength does not affect the five day lost list. If the geomagnetic field strength was a factor, it should have a positive, not negative correlation.

The sensor correlations using the five day lost list and lag procedure showed some differences from the two day lag analysis. Eglin, PARCS and NAVSPASUR start sending in more observations just as they did for the two day list except the maximum correlation for all of them occurs one day after the five day lost list increases. These three sensors also had stronger correlation coefficients than the two day list indicating that they are more responsive to five day lost list changes than two day lost list changes. Strong correlations with the five day lost list also included Eldorado as a sensor that responds to changes in the lost list. However, for the two day lost list, Eldorado had only a .094899 correlation with lag zero. For the five day list it showed .196402 with a negative lag of one. This indicates that Eldorado may respond slightly to changes in the five day lost list. The remaining sensors' correlations were not significant.

### Multiple Regression Causation Analysis

A stepwise variable selection procedure on the software package Statgraphics is used to perform the multiple linear regression. A stepwise assessment on an independent variable entering into the model is done by conducting an F-ratio test of 4.0 for a 95% confidence interval. By using the F-ratio test, the stepwise selection technique rejects independent variables which do not, in combination with other variables, add significance to the overall relationship. The goal of this procedure is to combine the causational effects of all the independent variables identified in the simple linear regression into one relationship. It is a goal to determine if an optimal mix of the independent variables can together explain a large portion of the variation in the lost satellite list.

TABLE 8

MULTIPLE LINEAR REGRESSION NO TRANSFORMATION  
FOR CAUSATION OF THE 2 DAY LOST LIST

| Independent<br>Variable<br>Added | BEST<br>LAG | Cumulative<br>R-Squared<br>Value |
|----------------------------------|-------------|----------------------------------|
| : F10 ACT                        | : 0         | : .05280                         |

DW = .987  
DF = 355  
MSE = 646.828  
R-Squared(ADJ)= .05013

Table 8 shows the results of using the best positive or

zero lag with no transformation of variables on the two day lost list. The two independent variables are used F10 BAR and F10 ACT. The stepwise selection technique rejects the F10 BAR because it did not add significantly in combination with F10 ACT to explain the lost 2 day lost list variance. The results of the multiple regression are suspect because the Durbin-Watson value was .987 implying that there is a violation of the independence of residuals assumption. This means that the R-Squared(ADJ) could be incorrect. To improve the DW value a Log transformation is used.

The results of the log transformation are shown in Table 9. The DW value got worse after this transformation. The next transformation is the method of first differences.

TABLE 9

MULTIPLE LINEAR REGRESSION LOG TRANSFORMATION  
FOR CAUSATION OF THE 2 DAY LOST LIST

| Independent<br>Variable<br>Added | BEST<br>LAG | Cumulative<br>R-Squared<br>Value |
|----------------------------------|-------------|----------------------------------|
| -----                            |             |                                  |
| : F10 ACT                        | : 0         | : .05218                         |
| -----                            |             |                                  |

DW = .389  
DF = 355  
MSE = .115716  
R-Squared(ADJ)= .04951

TABLE 10

MULTIPLE LINEAR REGRESSION DIFFERENCE TRANSFORMATION  
FOR CAUSATION OF THE 2 DAY LOST LIST

| Independent<br>Variable<br>Added | BEST<br>LAG | Cumulative<br>R-Squared<br>Value |
|----------------------------------|-------------|----------------------------------|
| : F10 ACT                        | : 0         | : .01433                         |

DW = 2.406  
DF = 349  
MSE = 635.746  
R-Squared(ADJ)= .01151

The method of first differences results in a DW value of 2.406, so it can be concluded that this relationship has less autocorrelation of residuals. The R-Squared value was only .01151. This means that the multiple linear regression with a difference transformation does not explain more variance than the simple linear regression.

TABLE 11

MULTIPLE LINEAR REGRESSION NO TRANSFORMATION  
FOR CAUSATION OF THE 5 DAY LOST LIST

| Independent<br>Variable<br>Added | BEST<br>LAG | Cumulative<br>R-Squared<br>Value | t-values |
|----------------------------------|-------------|----------------------------------|----------|
| : LOST 4                         | : 1         | : .32317                         | : 7.8430 |
| : LOST 2                         | : 3         | : .34643                         | : 3.3763 |
| : F10 ACT                        | : 0         | : .36302                         | : 2.9539 |

DW = .396  
DF = 335  
MSE = 416.749  
R-Squared(ADJ)= .35732

Table 11 shows the results of using the best positive or zero lag with no transformation of variables on the five day lost list. The five independent variables used are LOST 2, LOST 3, LOST 4, F10 BAR and F10 ACT. For the five day lost list the stepwise selection technique rejected LOST 3 AND the F10 BAR because they did not add significance to the relationship. The results of this multiple regression are suspect because of a Durbin-Watson value of only .396 implying that there is autocorrelation among the residuals. To improve the DW value a Log transformation is used.

The results of the multiple linear regression with log transformations of the variables are shown in Table 12.

TABLE 12  
MULTIPLE LINEAR REGRESSION LOG TRANSFORMATION  
FOR CAUSATION OF THE 5 DAY LOST LIST

| Independent<br>Variable<br>Added | BEST<br>LAG | Cumulative<br>R-Squared<br>Value | t-values |
|----------------------------------|-------------|----------------------------------|----------|
| : LOST 4                         | : 1         | : .26287                         | : 7.2807 |
| : LOST 2                         | : 3         | : .29281                         | : 3.7710 |

DW = .363  
DF = 336  
MSE = .167862  
R-Squared(ADJ)= .28860

The DW value got worse after this transformation. The next transformation attempted is the method of first differences.

TABLE 13

MULTIPLE LINEAR REGRESSION DIFFERENCE TRANSFORMATION  
FOR CAUSATION OF THE 5 DAY LOST LIST

| Independent<br>Variable<br>Added | BEST<br>LAG | Cumulative<br>R-Squared<br>Value | t-values |
|----------------------------------|-------------|----------------------------------|----------|
| : LOST 4                         | : 1         | : .19183                         | : 9.5369 |
| : LOST 3                         | : 0         | : .23940                         | : 4.5428 |

DW = 1.939  
DF = 330  
MSE = 72.2325  
R-Squared(ADJ)= .23479

The method of first differences results in a DW value of 1.939, so it can be concluded that this relationship has little or no autocorrelation of residuals. The R-Squared value is only .23940. This means that the multiple linear regression with a difference transformation does not explain more variance than the simple linear regression with the LOST 4 variable. The author reran simple linear regression using the method of first differences on LOST 4 for comparison, however the results were not significant.

#### Multiple Regression Forecasting Model

The stepwise variable selection procedure on the software package Statgraphics that is used to perform the multiple linear regression for causation analysis is also used for forecasting. The same F-ratio test of 4.0 for a 95% confidence interval was conducted to determine which inde-

pendent variable would enter the model. The goal of this procedure is to combine into one relationship all the independent variables identified in the simple linear regression as strongly correlated to changes in a lost list. Only positive lags, including zero, are used since the author is only interested in using values that are available at the time of the prediction. For example, a lag of -1 is not used since it refers to tomorrow's value of a particular variable. The author wants to know if an optimal mix of the independent variables can significantly forecast the number of lost satellite's one day ahead.

The results of the regression are in Table 14. These results use the best positive or zero lag with no transformation of variables. The results of this multiple regression are not suspect since none of the assumptions are violated.

TABLE 14

2 DAY LOST LIST PREDICTOR

| Independent<br>Variable<br>Added | BEST<br>POS<br>LAG | Cumulative<br>R-Squared<br>Value | Coefficient | t-values  |
|----------------------------------|--------------------|----------------------------------|-------------|-----------|
| : LOST 2                         | : 1                | : .27894                         | : .417428   | : 8.9126  |
| : EGL                            | : 1                | : .30937                         | : -.003665  | : -7.3204 |
| : LOST 5                         | : 1                | : .34436                         | : .193356   | : 3.7509  |
| : F10 BAR                        | : 1                | : .37049                         | : .209761   | : 2.6830  |
| : LOST 4                         | : 1                | : .38747                         | : -.348083  | : -2.7245 |
| : BLE                            | : 1                | : .40196                         | : .007539   | : 3.2477  |
| : ELD                            | : 1                | : .41290                         | : .011050   | : 3.6273  |
| : RBN                            | : 1                | : .42208                         | : -.006994  | : -2.7880 |
| : F10 ACT                        | : 1                | : .43337                         | : .141076   | : 2.5959  |

TABLE 14 (cont)

## 2 DAY LOST LIST PREDICTOR

CONSTANT =  $-.341589$   
 DW = 1.939  
 DF = 341  
 MSE = 390.207  
 MAPE = 20.3355  
 R-Squared(ADJ) = .4183

The adjusted R-Squared of .4183 indicates that this regression relationship explains 41.83% of the total variation in the two day lost list. The multiple linear regression MSE is 390.207 with a MAPE of 20.335, compares well with a NF1 method of MSE of 641.3704 and a MAPE of 27.263

TABLE 15

## 5 DAY LOST LIST PREDICTOR

| Independent<br>Variable<br>Added | BEST<br>POS<br>LAG | Cumulative<br>R-Squared<br>Value | Coefficient | t-values  |
|----------------------------------|--------------------|----------------------------------|-------------|-----------|
| : LOST 5                         | : 1                | : .86722                         | : .858838   | : 42.7273 |
| : LOST 4                         | : 1                | : .88995                         | : .841187   | : 9.3709  |
| : LOST 3                         | : 2                | : .89743                         | : -.267703  | : -4.9719 |

CONSTANT = 3.14624  
 DW = 1.8  
 DF = 339  
 MSE = 68.9474  
 MAPE = 10.59243  
 R-Squared(ADJ) = .89652

The results of the multiple linear regression forecast for the five day lost list are in Table 15. The results also use the best positive or zero lag with no transformation of variables. The results are not suspect since none

of the assumptions are violated. This means that the multiple linear regression with an MSE of 68.9474, MAPE of 10.592 and an adjusted R-Squared of .89652 indicates that this regression relationship explains 89.65% of the total variation in the five day lost list. The NF1 method has good but not better results. NF1 has a MSE of 92.350 and a MAPE of 12.809 for the five day lost list.

#### Time Series Forecasters

The following figures show the fluctuation of each of the lost lists through the two periods used for time series forecasting. The model set is from February 5 to June 15, 1988 and the test set is from July 11 to October 11, 1988. Only the two day lost list model set shows no trend in the data, while among the other three, only the five day model set trends downward.

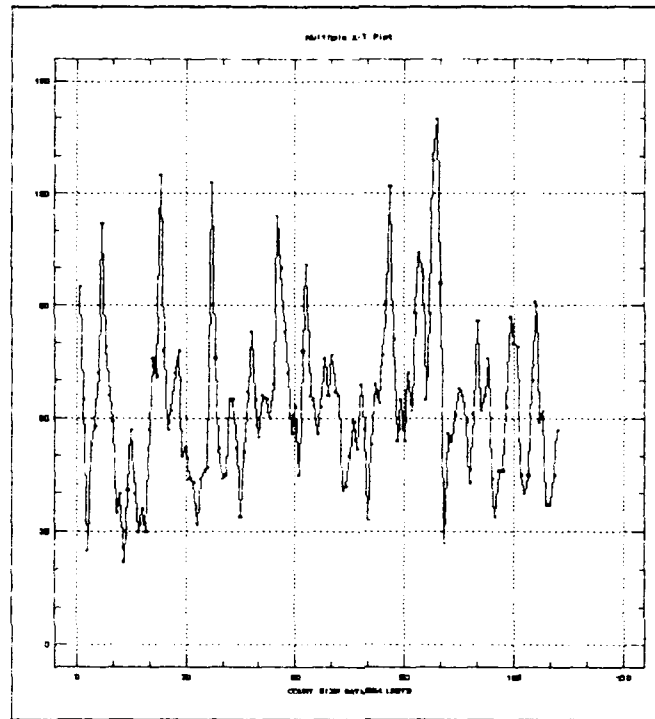


Figure 6. 2 Day Lost List Model Set

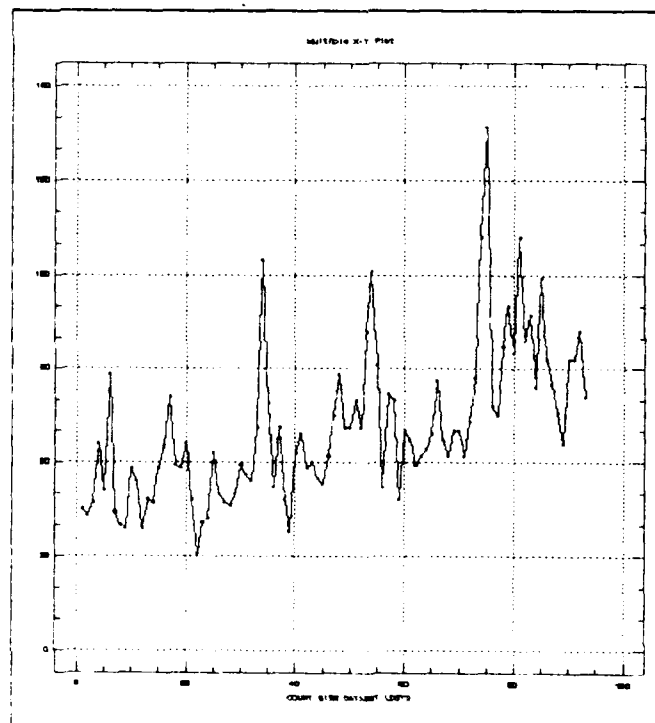


Figure 7. 2 Day Lost List Test Set

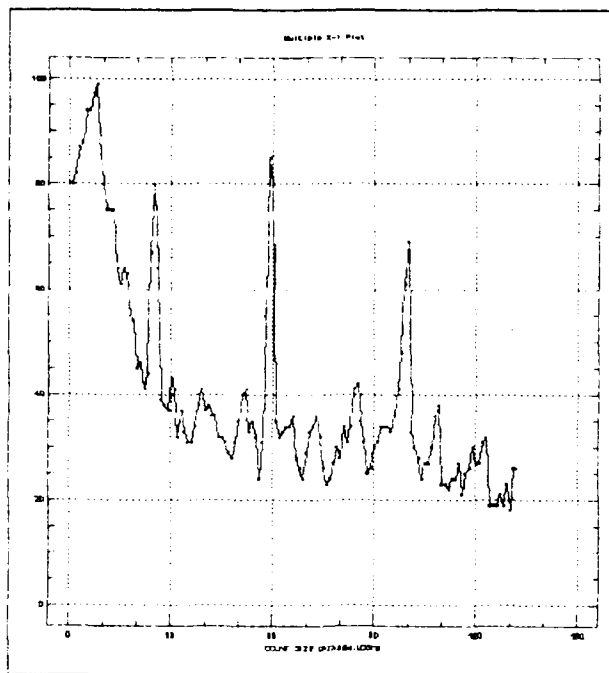


Figure 8. 5 Day Lost  
List Model Set

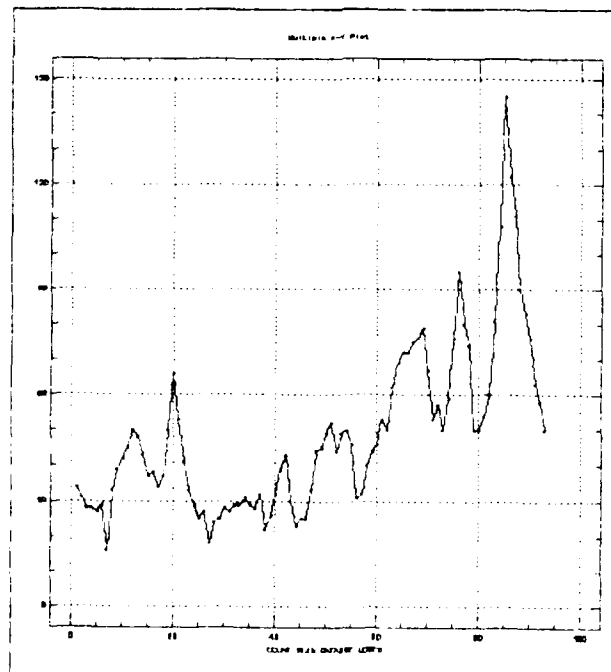


Figure 9. 5 Day Lost  
List Test Set

TABLE 16  
EXPONENTIAL LINEAR SMOOTHING RESULTS

| $\alpha$ | MSE     | MAPE    | LOST LIST | DATA SET |
|----------|---------|---------|-----------|----------|
| .12      | 530.518 | 30.2345 | 2 DAY *   | MODEL    |
| .12      | 406.547 | 19.8260 | 2 DAY     | TEST     |
| .05      | 396.228 | 18.8220 | 2 DAY *   | TEST     |
| .68      | 99.014  | 16.7959 | 5 DAY *   | MODEL    |
| .68      | 122.830 | 17.2058 | 5 DAY     | TEST     |
| .77      | 119.945 | 16.8142 | 5 DAY *   | TEST     |

\* BEST RESULTS FOR THAT LOST LIST DATA SET

The results of the exponential smoothing on the two and five day lost lists are shown in Table 16. The "best" alpha, found through trial and error using .01 increments, is the one that has the lowest MSE for that set of data. First the best alpha is found for the model set. Then that alpha is used on the test set to check for consistency of results. Finally a "best" alpha is found for the test set. This method did not provide better MSEs than the multiple linear regression model.

For the two day lost list, exponential smoothing uses low alpha values indicating these predictions are more dependent on the last forecast rather than the most recent data point when making the next forecast. This is because the relationship is:

$$F[t+1] = \alpha * X[t] + (1-\alpha) * F[t] \quad (21)$$

where

$F[t+1]$  is the next forecast

$\alpha$  is the inputted value between 0 and 1

$X[t]$  is the most recent data point

$F[t]$  is the last forecast

The results show the two day lost list is not as dependent on the previous values as much as the five day lost list. The five day lost list has the smallest MSE when the alpha rose to .68 for the model set and .77 for the test set. The size of the five day lost list is more a function of the previous day's size than any forecasted change.

TABLE 17

ADAPTIVE RESPONSE RATE EXPONENTIAL SMOOTHING RESULTS

| MSE     | MAPE   | LOST LIST | DATA SET |
|---------|--------|-----------|----------|
| 571.736 | 31.255 | 2 DAY     | MODEL    |
| 509.134 | 23.398 | 2 DAY     | TEST     |
| 139.193 | 19.959 | 5 DAY     | MODEL    |
| 254.019 | 21.151 | 5 DAY     | TEST     |

The adaptive response rate exponential smoothing using an adjustable alpha had MSEs that are higher than the MSEs of the exponential smoothing which used fixed alphas. The higher MSEs are shown in Table 17. The present alpha is

adjusted based on the error of the last forecast as well as to past adjustments made to the alpha. The failure of the adjustable alpha to forecast the data set as well as the fixed alpha is due to the fact that it weights more of the past changes it goes to predict changes in the lost lists.

The exponential smoothing models provide forecasts based on the assumption that the data is level. If the data is also trending, the exponential forecasts have a greater MSE than a technique, such as Holt's two-parameter smoothing, which takes into account a trend in the data. The results of Holt's two parameter smoothing are shown in Table 18.

TABLE 18  
HOLT'S SMOOTHING RESULTS

| $\alpha$ | $\beta$ | MSE     | MAPE    | LOST LIST | DATA SET |
|----------|---------|---------|---------|-----------|----------|
| .98      | .09     | 544.832 | 29.3974 | 2 DAY *   | MODEL    |
| .98      | .09     | 494.567 | 22.9716 | 2 DAY     | TEST     |
| .37      | .03     | 400.504 | 19.5392 | 2 DAY *   | TEST     |
| .99      | .02     | 71.705  | 13.4111 | 5 DAY *   | MODEL    |
| .99      | .02     | 104.084 | 16.1095 | 5 DAY     | TEST     |
| .99      | .03     | 103.997 | 15.9464 | 5 DAY *   | TEST     |

\* BEST RESULTS FOR THAT LOST LIST DATA SET

The alphas and betas that resulted in the lowest MSE for each set of data are shown. The alphas and betas in the

table are found through trial and error using .01 increments.

The results of Holt's method on the two day list are no better than results obtained by exponential smoothing. Holt's MSE for the two day model set is 544.832 while the exponential is 530.518. The best MSE for the two day test set is 400.504 using Holt's method, and 396.228 using exponential smoothing. The two day data sets exhibit little or no trend changes.

The MSEs for the five day lost lists were better using Holt's method than using exponential smoothing. The MSE went from 99.014 down to 71.705 for the five day model set when trending in the data is accounted for. The five day test set's MSE also decreased from 119.945 with exponential smoothing down to 103.997 with Holt's method.

Holt's two parameter smoothing takes into account only stationarity and trends in the data sets. If seasonality is also at work at changing the data pattern, then Winter's seasonal smoothing method should provide better results.

The results of Winter's seasonal smoothing are shown in Table 19. The alphas, betas, gammas and length of seasonality resulted in the lowest MSE for that set of data. The smoothing parameters in the table were found through trial and error using .01 increments. The length of seasonality is also found through trial and error with one day increments.

TABLE 19  
WINTER'S SEASONAL SMOOTHING RESULTS

| $\alpha$ | $\beta$ | $\tau$ | LENGTH<br>OF<br>SEASON | MSE       | MAPE      | LOST LIST DATA SET  |
|----------|---------|--------|------------------------|-----------|-----------|---------------------|
| : .66    | : .01   | : .99  | : 28                   | : 584.264 | : 31.4983 | : 2 DAY * : MODEL : |
| : .66    | : .01   | : .99  | : 28                   | : 625.709 | : 26.5010 | : 2 DAY : TEST :    |
| : .35    | : .03   | : .01  | : 2                    | : 406.390 | : 19.5350 | : 2 DAY * : TEST :  |
| : .99    | : .02   | : .01  | : 2                    | : 72.195  | : 13.4882 | : 5 DAY * : MODEL : |
| : .99    | : .02   | : .01  | : 2                    | : 105.255 | : 16.2877 | : 5 DAY : TEST :    |
| : .99    | : .03   | : .01  | : 2                    | : 105.168 | : 16.1228 | : 5 DAY * : TEST :  |

\* BEST RESULTS FOR THAT LOST LIST DATA SET

Winter's seasonal smoothing technique results are not better in MSE or MAPE than Holt's. Winter's MSE for the two day model set was 584.264 while Holt's MSE was 544.832. The MSE for the two day test set was 406.390 using Winter's and 400.504 using Holt's method.

The five day model lost list MSE using Winter's method was 72.195, for Holt's it was 71.705. The five day lost list test set had an MSE of 105.168 using Winter's method but 103.997 using Holt's method.

Table 20 shows the results of the NF1 method for both the two and five day lost lists over the model and test sets.

TABLE 20  
NAIVE FORECAST 1 RESULTS

| LOST LIST | DATA SET | MSE     | MAPE    |
|-----------|----------|---------|---------|
| 2 DAY     | MODEL    | 468.275 | 28.6017 |
| 2 DAY     | TEST     | 452.696 | 21.9035 |
| 5 DAY     | MODEL    | 68.412  | 12.9964 |
| 5 DAY     | TEST     | 97.848  | 15.2106 |

The NF1 provided better results than any time series model for the two day lost model set, five day model set and the five day test set. On the two day test set Exponential smoothing still has the best results with an MSE of 396.228 compares with NF1's MSE of 452.696.

Table 21 is a summary of all the forecasting methods results on the two day lost list.

TABLE 21  
SUMMARY OF 2 DAY LOST LIST FORECAST METHODS

| DATA SET | METHOD   | MSE     | MAPE   |
|----------|----------|---------|--------|
| MODEL    | EXPON    | 530.518 | 30.234 |
| MODEL    | ARRES    | 571.736 | 31.255 |
| MODEL    | HOLT'S   | 544.832 | 29.397 |
| MODEL    | WINTER'S | 584.264 | 31.498 |
| MODEL    | NF1      | 468.275 | 28.601 |
| TEST     | EXPON    | 396.228 | 18.822 |

TABLE 21 (cont)

## SUMMARY OF 2 DAY LOST LIST FORECAST METHODS

| DATA SET  | METHOD    | MSE     | MAPE   |
|-----------|-----------|---------|--------|
| TEST      | ARRES     | 509.134 | 23.393 |
| TEST      | HOLT'S    | 400.504 | 19.539 |
| TEST      | WINTER'S  | 406.390 | 19.535 |
| TEST      | NF1       | 452.696 | 21.903 |
| * YEAR 88 | MULT REGR | 390.207 | 20.335 |
| YEAR 88   | NF1       | 641.370 | 27.263 |

\* BEST RESULTS

The best method for forecasting is multiple regression with a MSE of 390.207. This method had a low MAPE of 20.335 over the entire 1988 data set.

Table 22 is a summary of all the forecasting methods results on the five day lost list.

TABLE 22

## SUMMARY OF 5 DAY LOST LIST FORECAST METHODS

| DATA SET | METHOD   | MSE     | MAPE   |
|----------|----------|---------|--------|
| MODEL    | EXPON    | 99.014  | 16.795 |
| MODEL    | ARRES    | 139.193 | 19.959 |
| MODEL    | HOLT'S   | 71.705  | 13.411 |
| MODEL    | WINTER'S | 72.195  | 13.488 |
| MODEL    | NF1      | 68.412  | 12.996 |

TABLE 22 (cont)

## SUMMARY OF 5 DAY LOST LIST FORECAST METHODS

| DATA SET      | METHOD      | MSE       | MAPE     |
|---------------|-------------|-----------|----------|
| : TEST :      | EXPON :     | 119.945 : | 16.814 : |
| : TEST :      | ARRES :     | 254.019 : | 21.151 : |
| : TEST :      | HOLT'S :    | 103.997 : | 15.946 : |
| : TEST :      | WINTER'S :  | 105.168 : | 16.122 : |
| : TEST :      | NF1 :       | 97.848 :  | 15.210 : |
| : * YEAR 88 : | MULT REGR : | 68.947 :  | 10.592 : |
| : YEAR 88 :   | NF1 :       | 92.350 :  | 12.808 : |

\* BEST RESULTS

The best method for forecasting is multiple regression with a MSE of 68.947. This method had a low MAPE of 10.592 over the entire 1988 data set. The NF1 method is a close second with a MSE of 97.848 and MAPE of 12.808.

## VI. Conclusions and Recommendations

### Conclusions

The results of this study reveal several interesting facts about what does and does not cause the lost lists to increase. Causation analysis, using simple linear regression, reveals that changes in the lost lists are partially due to changes in solar activity. However, due to the low correlation, it is likely that solar activity is one of several causes in determining the size of the lost lists. The results also show that geomagnetic field strength does not cause the lost lists to change. None of the regressions show geomagnetic field strength as a cause of variance in either the two or five day lost lists.

Another result of causation analysis is that a decrease in the number of observations arriving at the SSC does not cause the lost lists to increase. This is a surprising result. However, when the lost lists increase, some of the sensors send in more observations. Specifically, when the two day lost list increases, three sensors respond by increasing their number of daily observations. When the five day lost list increases, four sensors respond by sending in more observations. At a time when the SSC needs more observations, the most capable phased arrays in the network are not responding to increasing tasking requirements.

The final result of causation analysis worth noting is

that there is a high percentage of satellites that begin on the two day lost list and, three days later, end up on the five day list. At least forty five percent of the satellites on the two day list will be on the five day lost list.

The prediction analysis yields good predictors for both lost lists as well as information on lost list data patterns. Explanatory forecasting produces a better predictor than any of the time series models.

In the case of the two day lost list the multiple regression model explains 41.83% of the variance with an MSE of 390.207. For the five day list, the same regression technique explains 89.65% with an MSE of 68.9474.

The time series analysis shows that the two day lost list has a strong stationary pattern while the five day list contains a trend. The best time-series predictor for the two day lost list is exponential smoothing. For the five day lost list the best predictor is Holt's two parameter smoothing. No seasonality is found in any of the four data sets in this time-series analysis.

### Recommendations

In the progression of this thesis the author has discovered several areas that hold promise for future research. First, the time series approach could be expanded. Decomposition methods could be used to divide the data into subpatterns that identify each component of the time series sepa-

rately. Such a breakdown would improve accuracy in forecasting and aid in better understanding the behavior of the series. Also, the inclusion of other time series techniques such as Box Jenkins, Univariate and Multivariate, may provide better results.

The second recommendation is to obtain a data set longer than two years with more independent variables. Inclusion of independent variables, such as total satellite population and number of current satellite breakups, would give an indication of how the lost list changes when the sensors are busy with other tasking requirements. The seven sensor variables could be subdivided into different correlation categories based on their ASTAT correlation with the satellite's element set. Using a longer data set may also allow identification of the seasonality of the eleven year solar cycle.

APPENDIX A: Data Set

|                         | Page |
|-------------------------|------|
| 1988 Data Set . . . . . | 73   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 01-Jan-88 |       |       |       |       | 23       | 2857   |
| 02-Jan-88 | 45    | 8     | 14    | 72    | 43       | 2429   |
| 03-Jan-88 | 104   | 22    | 7     | 60    | 46       | 2829   |
| 04-Jan-88 | 85    | 30    | 10    | 62    | 48       | 3070   |
| 05-Jan-88 | 60    | 27    | 13    | 59    | 32       | 9320   |
| 06-Jan-88 | 95    | 29    | 12    | 65    | 23       | 6753   |
| 07-Jan-88 | 83    | 24    | 18    | 64    | 37       | 2001   |
| 08-Jan-88 | 62    | 43    | 16    | 74    | 24       | 1318   |
| 09-Jan-88 | 104   | 32    | 24    | 79    | 32       | 1217   |
| 10-Jan-88 | 51    | 21    | 5     | 81    | 23       | 2752   |
| 11-Jan-88 | 59    | 9     | 10    | 69    | 35       | 2404   |
| 12-Jan-88 | 63    | 22    | 2     | 75    | 22       | 1547   |
| 13-Jan-88 | 69    | 30    | 17    | 71    | 28       | 715    |
| 14-Jan-88 | 67    | 23    | 19    | 74    | 56       | 2828   |
| 15-Jan-88 | 68    | 23    | 11    | 83    | 70       | 1831   |
| 16-Jan-88 | 87    | 20    | 10    | 86    | 39       | 1390   |
| 17-Jan-88 | 99    | 26    | 10    | 78    | 51       | 2561   |
| 18-Jan-88 | 154   | 28    | 15    | 78    | 77       | 3173   |
| 19-Jan-88 | 151   | 38    | 8     | 83    | 50       | 2720   |
| 20-Jan-88 | 98    | 98    | 17    | 81    | 67       | 5673   |
| 21-Jan-88 | 141   | 32    | 51    | 84    | 44       | 2118   |
| 22-Jan-88 | 60    | 52    | 20    | 122   | 49       | 3071   |
| 23-Jan-88 | 66    | 10    | 6     | 81    | 26       | 1575   |
| 24-Jan-88 | 62    | 23    | 6     | 78    | 67       | 2571   |
| 25-Jan-88 | 103   | 12    | 6     | 69    | 53       | 2586   |
| 26-Jan-88 | 71    | 29    | 7     | 67    | 47       | 8559   |
| 27-Jan-88 | 79    | 34    | 12    | 68    | 42       | 2380   |
| 28-Jan-88 | 87    | 16    | 19    | 65    | 46       | 1996   |
| 29-Jan-88 | 68    | 28    | 12    | 68    | 30       | 1291   |
| 30-Jan-88 | 104   | 25    | 10    | 69    | 36       | 2651   |
| 31-Jan-88 | 77    | 24    | 6     | 65    | 60       | 2273   |
| 01-Feb-88 | 92    | 25    | 17    | 66    | 31       | 1403   |
| 02-Feb-88 | 79    | 22    | 12    | 70    | 54       | 3514   |
| 03-Feb-88 | 59    | 21    | 10    | 71    | 40       | 842    |
| 04-Feb-88 |       |       |       |       |          |        |
| 05-Feb-88 | 95    | 25    | 12    | 80    | 17       | 8536   |
| 06-Feb-88 | 65    | 19    | 13    | 82    | 37       | 9525   |
| 07-Feb-88 | 25    | 20    | 11    | 87    | 48       | 5499   |
| 08-Feb-88 | 53    | 9     | 9     | 88    | 52       | 6621   |
| 09-Feb-88 | 58    | 26    | 3     | 94    | 46       | 1649   |
| 10-Feb-88 | 72    | 37    | 14    | 94    | 58       | 6544   |
| 11-Feb-88 | 112   | 40    | 19    | 97    | 56       | 3255   |
| 12-Feb-88 | 79    | 28    | 13    | 99    | 48       | 2641   |
| 13-Feb-88 | 66    | 16    | 4     | 89    | 34       | 2609   |
| 14-Feb-88 | 59    | 10    | 5     | 80    | 58       | 2321   |
| 15-Feb-88 | 35    | 17    | 5     | 75    | 78       | 11676  |
| 16-Feb-88 | 40    | 7     | 4     | 75    | 21       | 1480   |
| 17-Feb-88 | 22    | 11    | 3     | 75    | 40       | 2107   |
| 18-Feb-88 | 41    | 7     | 8     | 64    | 41       | 1303   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 19-Feb-88 | 57    | 15    | 6     | 61    | 34       | 983    |
| 20-Feb-88 | 40    | 18    | 7     | 64    | 35       | 2971   |
| 21-Feb-88 | 30    | 13    | 10    | 63    | 35       | 3178   |
| 22-Feb-88 | 36    | 10    | 4     | 55    | 39       | 1843   |
| 23-Feb-88 | 30    | 9     | 4     | 54    | 35       | 10333  |
| 24-Feb-88 | 57    | 12    | 7     | 45    | 25       | 950    |
| 25-Feb-88 | 76    | 23    | 8     | 46    | 28       | 2086   |
| 26-Feb-88 | 71    | 43    | 9     | 41    | 39       | 1378   |
| 27-Feb-88 | 125   | 49    | 37    | 44    | 37       | 3195   |
| 28-Feb-88 | 78    | 51    | 27    | 67    | 48       | 968    |
| 29-Feb-88 | 57    | 26    | 26    | 80    | 82       | 3328   |
| 01-Mar-88 | 62    | 17    | 10    | 64    | 80       | 2512   |
| 02-Mar-88 | 72    | 14    | 7     | 39    | 62       | 11831  |
| 03-Mar-88 | 78    | 25    | 4     | 38    | 25       | 7303   |
| 04-Mar-88 | 50    | 21    | 18    | 37    | 37       | 20900  |
| 05-Mar-88 | 52    | 20    | 11    | 43    | 62       | 8739   |
| 06-Mar-88 | 44    | 17    | 6     | 41    | 82       | 12185  |
| 07-Mar-88 | 43    | 9     | 7     | 32    | 77       | 3470   |
| 08-Mar-88 | 32    | 12    | 1     | 37    | 76       | 2388   |
| 09-Mar-88 | 44    | 7     | 5     | 33    | 45       | 2871   |
| 10-Mar-88 | 46    | 8     | 4     | 31    | 49       | 3052   |
| 11-Mar-88 | 47    | 27    | 7     | 31    | 34       | 1416   |
| 12-Mar-88 | 123   | 18    | 11    | 34    | 36       | 2428   |
| 13-Mar-88 | 76    | 38    | 13    | 38    | 23       | 10088  |
| 14-Mar-88 | 52    | 15    | 15    | 41    | 62       | 2081   |
| 15-Mar-88 | 44    | 7     | 5     | 37    | 61       | 5897   |
| 16-Mar-88 | 45    | 11    | 6     | 38    | 44       | 1880   |
| 17-Mar-88 | 65    | 5     | 5     | 36    | 28       | 1315   |
| 18-Mar-88 | 65    | 19    | 3     | 36    | 39       | 22459  |
| 19-Mar-88 | 52    | 18    | 10    | 32    | 64       | 1318   |
| 20-Mar-88 | 34    | 11    | 5     | 32    | 48       | 3754   |
| 21-Mar-88 | 51    | 5     | 6     | 31    | 47       | 1184   |
| 22-Mar-88 | 67    | 15    | 1     | 29    | 70       | 3234   |
| 23-Mar-88 | 83    | 21    | 8     | 28    | 47       | 2364   |
| 24-Mar-88 | 65    | 20    | 7     | 31    | 50       | 1534   |
| 25-Mar-88 | 55    | 27    | 11    | 35    | 63       | 2395   |
| 26-Mar-88 | 66    | 18    | 19    | 40    | 27       | 745    |
| 27-Mar-88 | 65    | 29    | 5     | 41    | 35       | 893    |
| 28-Mar-88 | 60    | 13    | 10    | 33    | 50       | 5001   |
| 29-Mar-88 | 69    | 11    | 7     | 35    | 43       | 4493   |
| 30-Mar-88 | 114   | 10    | 1     | 32    | 62       | 3105   |
| 31-Mar-88 | 100   | 52    | 9     | 24    | 31       | 883    |
| 01-Apr-88 | 83    | 66    | 37    | 31    | 37       | 1534   |
| 02-Apr-88 | 72    | 46    | 40    | 55    | 60       | 2023   |
| 03-Apr-88 | 56    | 28    | 33    | 85    | 68       | 2608   |
| 04-Apr-88 | 63    | 15    | 15    | 80    | 49       | 2130   |
| 05-Apr-88 | 45    | 11    | 9     | 35    | 29       | 1345   |
| 06-Apr-88 | 78    | 25    | 8     | 32    | 34       | 3424   |
| 07-Apr-88 | 101   | 32    | 10    | 33    | 65       | 4390   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 08-Apr-88 | 66    | 33    | 11    | 34    | 50       | 8010   |
| 09-Apr-88 | 65    | 27    | 16    | 34    | 44       | 2577   |
| 10-Apr-88 | 56    | 12    | 9     | 36    | 61       | 2389   |
| 11-Apr-88 | 63    | 18    | 5     | 28    | 42       | 1786   |
| 12-Apr-88 | 76    | 25    | 10    | 26    | 59       | 1920   |
| 13-Apr-88 | 66    | 20    | 10    | 24    | 64       | 5838   |
| 14-Apr-88 | 77    | 16    | 11    | 29    | 33       | 2056   |
| 15-Apr-88 | 67    | 39    | 9     | 33    | 32       | 748    |
| 16-Apr-88 | 66    | 25    | 10    | 34    | 58       | 1929   |
| 17-Apr-88 | 41    | 22    | 11    | 36    | 59       | 1770   |
| 18-Apr-88 | 42    | 15    | 6     | 32    | 63       | 1102   |
| 19-Apr-88 | 50    | 12    | 8     | 26    | 56       | 1989   |
| 20-Apr-88 | 59    | 16    | 12    | 23    | 46       | 1679   |
| 21-Apr-88 | 52    | 12    | 5     | 24    | 55       | 929    |
| 22-Apr-88 | 69    | 17    | 8     | 27    | 54       | 2646   |
| 23-Apr-88 | 57    | 20    | 4     | 30    | 49       | 1639   |
| 24-Apr-88 | 33    | 15    | 7     | 28    | 50       | 1515   |
| 25-Apr-88 | 53    | 12    | 5     | 34    | 32       | 885    |
| 26-Apr-88 | 69    | 30    | 8     | 31    | 61       | 1952   |
| 27-Apr-88 | 64    | 29    | 18    | 34    | 80       | 3043   |
| 28-Apr-88 | 77    | 22    | 19    | 41    | 69       | 2500   |
| 29-Apr-88 | 91    | 15    | 11    | 42    | 65       | 3602   |
| 30-Apr-88 | 122   | 12    | 6     | 35    | 53       | 1856   |
| 01-May-88 | 81    | 13    | 5     | 31    | 31       | 1468   |
| 02-May-88 | 54    | 12    | 4     | 25    | 27       | 1908   |
| 03-May-88 | 65    | 15    | 6     | 26    | 29       | 2243   |
| 04-May-88 | 54    | 23    | 10    | 30    | 52       | 4093   |
| 05-May-88 | 72    | 12    | 13    | 31    | 59       | 2356   |
| 06-May-88 | 62    | 28    | 5     | 34    | 50       | 2661   |
| 07-May-88 | 88    | 19    | 10    | 34    | 45       | 1485   |
| 08-May-88 | 104   | 31    | 8     | 34    | 48       | 1279   |
| 09-May-88 | 99    | 24    | 10    | 33    | 36       | 864    |
| 10-May-88 | 65    | 41    | 12    | 36    | 43       | 1966   |
| 11-May-88 | 88    | 22    | 20    | 41    | 45       | 3104   |
| 12-May-88 | 129   | 43    | 16    | 48    | 59       | 4089   |
| 13-May-88 | 140   | 104   | 42    | 61    | 53       | 2534   |
| 14-May-88 | 96    | 68    | 24    | 69    | 66       | 2220   |
| 15-May-88 | 27    | 14    | 16    | 33    | 51       | 1579   |
| 16-May-88 | 56    | 10    | 8     | 30    | 45       | 13138  |
| 17-May-88 | 54    | 13    | 4     | 28    | 55       | 2042   |
| 18-May-88 | 61    | 16    | 6     | 24    | 50       | 612    |
| 19-May-88 | 68    | 15    | 10    | 27    | 55       | 1402   |
| 20-May-88 | 66    | 26    | 7     | 27    | 64       | 8286   |
| 21-May-88 | 59    | 24    | 13    | 30    | 45       | 1398   |
| 22-May-88 | 43    | 12    | 12    | 36    | 80       | 7374   |
| 23-May-88 | 61    | 23    | 9     | 38    | 57       | 2445   |
| 24-May-88 | 86    | 21    | 9     | 23    | 51       | 1839   |
| 25-May-88 | 62    | 12    | 7     | 23    | 62       | 2058   |
| 26-May-88 | 66    | 13    | 7     | 22    | 43       | 1246   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 27-May-88 | 76    | 29    | 8     | 24    | 35       | 5350   |
| 28-May-88 | 44    | 22    | 16    | 24    | 24       | 1657   |
| 29-May-88 | 34    | 16    | 9     | 27    | 28       | 1191   |
| 30-May-88 | 46    | 10    | 8     | 21    | 30       | 1936   |
| 31-May-88 | 46    | 20    | 7     | 25    | 32       | 655    |
| 01-Jun-88 | 63    | 23    | 14    | 26    | 48       | 794    |
| 02-Jun-88 | 87    | 16    | 6     | 30    | 58       | 2053   |
| 03-Jun-88 | 80    | 35    | 4     | 27    | 24       | 842    |
| 04-Jun-88 | 79    | 43    | 21    | 27    | 29       | 2349   |
| 05-Jun-88 | 45    | 27    | 12    | 31    | 40       | 1268   |
| 06-Jun-88 | 40    | 13    | 12    | 32    | 66       | 3589   |
| 07-Jun-88 | 45    | 11    | 4     | 19    | 53       | 4124   |
| 08-Jun-88 | 70    | 23    | 6     | 19    | 46       | 1949   |
| 09-Jun-88 | 91    | 17    | 6     | 19    | 60       | 8179   |
| 10-Jun-88 | 59    | 23    | 5     | 21    | 39       | 9101   |
| 11-Jun-88 | 62    | 11    | 11    | 19    | 32       | 1692   |
| 12-Jun-88 | 37    | 21    | 5     | 23    | 35       | 1434   |
| 13-Jun-88 | 37    | 17    | 12    | 18    | 36       | 14065  |
| 14-Jun-88 | 45    | 20    | 8     | 26    | 56       | 6095   |
| 15-Jun-88 | 57    | 19    | 17    | 26    | 57       | 3023   |
| 16-Jun-88 |       |       |       |       | 8        | 2122   |
| 17-Jun-88 |       |       |       |       | 25       | 1134   |
| 18-Jun-88 | 102   | 45    | 35    | 37    | 43       | 7510   |
| 19-Jun-88 | 41    | 30    | 12    | 44    | 46       | 1255   |
| 20-Jun-88 | 38    | 15    | 10    | 38    | 48       | 6027   |
| 21-Jun-88 | 59    | 16    | 6     | 29    | 32       | 2348   |
| 22-Jun-88 | 66    | 13    | 5     | 28    | 58       | 3996   |
| 23-Jun-88 | 52    | 24    | 9     | 26    | 75       | 6213   |
| 24-Jun-88 | 44    | 20    | 16    | 27    | 45       | 2596   |
| 25-Jun-88 | 76    | 24    | 13    | 34    | 49       | 1641   |
| 26-Jun-88 | 56    | 34    | 12    | 30    | 46       | 1968   |
| 27-Jun-88 | 40    | 9     | 6     | 27    | 45       | 1871   |
| 28-Jun-88 | 65    | 17    | 8     | 24    | 12       | 611    |
| 29-Jun-88 |       |       |       |       | 19       | 3668   |
| 30-Jun-88 | 72    | 21    | 9     | 25    | 60       | 3726   |
| 01-Jul-88 | 50    | 21    | 13    | 23    | 42       | 1874   |
| 02-Jul-88 | 63    | 14    | 7     | 20    | 59       | 2357   |
| 03-Jul-88 | 48    | 12    | 5     | 18    | 36       | 1732   |
| 04-Jul-88 | 52    | 9     | 1     | 17    | 36       | 3780   |
| 05-Jul-88 | 77    | 10    | 4     | 15    | 37       | 1438   |
| 06-Jul-88 | 68    | 29    | 5     | 16    | 48       | 2854   |
| 07-Jul-88 | 89    | 28    | 19    | 21    | 53       | 2967   |
| 08-Jul-88 | 56    | 37    | 15    | 32    | 60       | 2853   |
| 09-Jul-88 | 39    | 17    | 14    | 35    | 45       | 1345   |
| 10-Jul-88 |       |       |       |       | 42       | 4013   |
| 11-Jul-88 | 45    | 12    | 5     | 34    | 39       | 1418   |
| 12-Jul-88 | 43    | 17    | 4     | 31    | 37       | 1271   |
| 13-Jul-88 | 47    | 12    | 7     | 28    | 39       | 1986   |
| 14-Jul-88 | 66    | 28    | 8     | 28    | 41       | 2819   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 15-Jul-88 | 51    | 22    | 8     | 27    | 23       | 214    |
| 16-Jul-88 | 88    | 26    | 12    | 29    | 32       | 1958   |
| 17-Jul-88 | 44    | 23    | 13    | 16    | 28       | 427    |
| 18-Jul-88 | 40    | 23    | 9     | 33    | 27       | 492    |
| 19-Jul-88 | 39    | 12    | 14    | 39    | 34       | 887    |
| 20-Jul-88 | 58    | 20    | 9     | 42    | 17       | 410    |
| 21-Jul-88 | 54    | 41    | 14    | 45    | 35       | 714    |
| 22-Jul-88 | 39    | 18    | 10    | 50    | 43       | 1249   |
| 23-Jul-88 | 48    | 16    | 9     | 48    | 36       | 1046   |
| 24-Jul-88 | 47    | 10    | 10    | 43    | 47       | 1012   |
| 25-Jul-88 | 58    | 12    | 5     | 37    | 43       | 1947   |
| 26-Jul-88 | 65    | 25    | 5     | 38    | 29       | 2612   |
| 27-Jul-88 | 81    | 34    | 18    | 34    | 47       | 2033   |
| 28-Jul-88 | 59    | 35    | 23    | 37    | 37       | 937    |
| 29-Jul-88 | 58    | 31    | 30    | 50    | 24       | 842    |
| 30-Jul-88 | 66    | 30    | 23    | 66    | 32       | 1615   |
| 31-Jul-88 | 48    | 21    | 14    | 53    | 33       | 1028   |
| 01-Aug-88 | 31    | 20    | 14    | 41    | 81       | 3944   |
| 02-Aug-88 | 41    | 9     | 5     | 33    | 59       | 2036   |
| 03-Aug-88 | 42    | 15    | 5     | 29    | 42       | 1640   |
| 04-Aug-88 | 63    | 16    | 11    | 25    | 46       | 2129   |
| 05-Aug-88 | 50    | 27    | 7     | 27    | 35       | 740    |
| 06-Aug-88 | 47    | 14    | 8     | 18    | 50       | 1164   |
| 07-Aug-88 | 46    | 11    | 8     | 24    | 52       | 10789  |
| 08-Aug-88 | 50    | 9     | 9     | 25    | 64       | 4081   |
| 09-Aug-88 | 59    | 16    | 2     | 28    | 45       | 1594   |
| 10-Aug-88 | 56    | 21    | 8     | 27    | 24       | 1651   |
| 11-Aug-88 | 54    | 20    | 8     | 29    | 52       | 3865   |
| 12-Aug-88 | 71    | 21    | 9     | 29    | 22       | 538    |
| 13-Aug-88 | 125   | 25    | 11    | 31    | 38       | 1114   |
| 14-Aug-88 | 79    | 30    | 10    | 29    | 31       | 782    |
| 15-Aug-88 | 52    | 22    | 13    | 28    | 45       | 1688   |
| 16-Aug-88 | 71    | 16    | 6     | 32    | 48       | 1040   |
| 17-Aug-88 | 48    | 25    | 9     | 22    | 37       | 1079   |
| 18-Aug-88 | 38    | 23    | 16    | 26    | 24       | 1225   |
| 19-Aug-88 | 63    | 22    | 16    | 32    | 33       | 551    |
| 20-Aug-88 | 69    | 41    | 17    | 39    | 60       | 3000   |
| 21-Aug-88 | 58    | 26    | 19    | 43    | 34       | 1076   |
| 22-Aug-88 | 60    | 25    | 14    | 30    | 59       | 1734   |
| 23-Aug-88 | 55    | 19    | 4     | 23    | 57       | 1252   |
| 24-Aug-88 | 53    | 21    | 12    | 25    | 41       | 1155   |
| 25-Aug-88 | 62    | 18    | 9     | 25    | 42       | 3711   |
| 26-Aug-88 | 75    | 31    | 19    | 33    | 37       | 1363   |
| 27-Aug-88 | 88    | 37    | 21    | 44    | 53       | 1343   |
| 28-Aug-88 | 71    | 42    | 17    | 45    | 68       | 1516   |
| 29-Aug-88 | 71    | 31    | 20    | 49    | 45       | 1239   |
| 30-Aug-88 | 80    | 31    | 15    | 52    | 41       | 2532   |
| 31-Aug-88 | 71    | 38    | 19    | 44    | 35       | 1736   |
| 01-Sep-88 | 102   | 42    | 21    | 49    | 65       | 4056   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 02-Sep-88 | 121   | 30    | 19    | 50    | 55       | 1131   |
| 03-Sep-88 | 91    | 40    | 16    | 46    | 45       | 801    |
| 04-Sep-88 | 52    | 50    | 18    | 31    | 37       | 774    |
| 05-Sep-88 | 82    | 23    | 23    | 32    | 45       | 728    |
| 06-Sep-88 | 80    | 21    | 13    | 40    | 46       | 1368   |
| 07-Sep-88 | 48    | 39    | 18    | 44    | 49       | 1672   |
| 08-Sep-88 | 70    | 14    | 14    | 46    | 50       | 2694   |
| 09-Sep-88 | 67    | 35    | 5     | 53    | 62       | 1549   |
| 10-Sep-88 | 59    | 35    | 25    | 50    | 30       | 701    |
| 11-Sep-88 | 62    | 29    | 15    | 62    | 29       | 484    |
| 12-Sep-88 | 64    | 22    | 16    | 69    | 21       | 243    |
| 13-Sep-88 | 69    | 31    | 10    | 72    | 26       | 544    |
| 14-Sep-88 | 86    | 27    | 18    | 72    | 56       | 1503   |
| 15-Sep-88 | 67    | 27    | 12    | 75    | 34       | 544    |
| 16-Sep-88 | 62    | 23    | 9     | 76    | 47       | 839    |
| 17-Sep-88 | 70    | 32    | 11    | 79    | 26       | 598    |
| 18-Sep-88 | 70    | 19    | 9     | 67    | 49       | 1336   |
| 19-Sep-88 | 62    | 14    | 8     | 53    | 41       | 2550   |
| 20-Sep-88 | 73    | 20    | 6     | 57    | 34       | 5251   |
| 21-Sep-88 | 87    | 27    | 10    | 50    | 37       | 584    |
| 22-Sep-88 | 132   | 46    | 30    | 59    | 53       | 765    |
| 23-Sep-88 | 167   | 72    | 35    | 76    | 32       | 2050   |
| 24-Sep-88 | 78    | 48    | 32    | 95    | 56       | 2287   |
| 25-Sep-88 | 75    | 25    | 25    | 80    | 42       | 1632   |
| 26-Sep-88 | 97    | 29    | 14    | 74    | 39       | 3808   |
| 27-Sep-88 | 110   | 26    | 13    | 50    | 53       | 2220   |
| 28-Sep-88 | 95    | 21    | 13    | 50    | 64       | 1735   |
| 29-Sep-88 | 132   | 17    | 11    | 54    | 57       | 870    |
| 30-Sep-88 | 99    | 89    | 14    | 60    | 54       | 1754   |
| 01-Oct-88 | 107   | 56    | 63    | 81    | 61       | 1984   |
| 02-Oct-88 | 84    | 40    | 39    | 108   | 64       | 1938   |
| 03-Oct-88 | 119   | 32    | 25    | 145   | 57       | 1734   |
| 04-Oct-88 | 93    | 41    | 13    | 122   | 38       | 1534   |
| 05-Oct-88 | 85    | 53    | 26    | 111   | 67       | 1997   |
| 06-Oct-88 | 76    | 28    | 26    | 90    | 53       | 3001   |
| 07-Oct-88 | 66    | 41    | 16    | 83    | 49       | 1855   |
| 08-Oct-88 | 93    | 40    | 31    | 76    | 27       | 2200   |
| 09-Oct-88 | 93    | 29    | 17    | 63    | 71       | 2991   |
| 10-Oct-88 | 102   | 15    | 8     | 58    | 80       | 2955   |
| 11-Oct-88 | 81    | 20    | 3     | 50    | 84       | 2598   |
| 12-Oct-88 |       |       |       |       | 15       | 2106   |
| 13-Oct-88 |       |       |       |       | 16       | 964    |
| 14-Oct-88 |       |       |       |       | 34       | 2274   |
| 15-Oct-88 | 98    | 80    | 87    | 95    | 7        | 846    |
| 16-Oct-88 | 60    | 49    | 66    | 117   | 73       | 2657   |
| 17-Oct-88 | 73    | 18    | 24    | 129   | 73       | 4078   |
| 18-Oct-88 | 100   | 28    | 14    | 122   | 60       | 2139   |
| 19-Oct-88 | 88    | 41    | 12    | 105   | 67       | 2439   |
| 20-Oct-88 | 120   | 24    | 15    | 84    | 84       | 3859   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 21-Oct-88 | 143   | 47    | 11    | 92    | 64       | 2473   |
| 22-Oct-88 | 134   | 83    | 25    | 104   | 67       | 3694   |
| 23-Oct-88 | 113   | 56    | 50    | 94    | 89       | 4148   |
| 24-Oct-88 | 46    | 28    | 13    | 65    | 92       | 12843  |
| 25-Oct-88 | 75    | 24    | 17    | 66    | 47       | 1901   |
| 26-Oct-88 | 192   | 30    | 14    | 72    | 80       | 4101   |
| 27-Oct-88 | 87    | 63    | 14    | 81    | 82       | 7202   |
| 28-Oct-88 | 86    | 29    | 20    | 82    | 72       | 6992   |
| 29-Oct-88 | 68    | 37    | 12    | 80    | 90       | 4281   |
| 30-Oct-88 | 63    | 23    | 16    | 68    | 105      | 5178   |
| 31-Oct-88 | 51    | 23    | 11    | 52    | 67       | 3634   |
| 01-Nov-88 | 45    | 19    | 13    | 52    | 89       | 14333  |
| 02-Nov-88 | 78    | 22    | 14    | 57    | 65       | 2334   |
| 03-Nov-88 | 165   | 33    | 11    | 57    | 75       | 1314   |
| 04-Nov-88 | 142   | 64    | 16    | 59    | 69       | 1915   |
| 05-Nov-88 | 119   | 53    | 28    | 64    | 62       | 2262   |
| 06-Nov-88 | 111   | 48    | 26    | 80    | 38       | 1629   |
| 07-Nov-88 | 79    | 55    | 24    | 93    | 97       | 4395   |
| 08-Nov-88 | 93    | 50    | 23    | 89    | 49       | 3042   |
| 09-Nov-88 | 82    | 42    | 33    | 91    | 57       | 3804   |
| 10-Nov-88 | 69    | 19    | 21    | 94    | 68       | 2284   |
| 11-Nov-88 | 66    | 21    | 10    | 85    | 49       | 1449   |
| 12-Nov-88 | 74    | 17    | 11    | 84    | 66       | 3568   |
| 13-Nov-88 | 46    | 13    | 7     | 74    | 79       | 2668   |
| 14-Nov-88 | 60    | 12    | 3     | 57    | 84       | 2901   |
| 15-Nov-88 | 53    | 12    | 3     | 58    | 71       | 4615   |
| 16-Nov-88 | 66    | 24    | 8     | 58    | 67       | 3538   |
| 17-Nov-88 | 126   | 17    | 7     | 54    | 52       | 2335   |
| 18-Nov-88 | 81    | 52    | 7     | 53    | 54       | 2089   |
| 19-Nov-88 | 88    | 23    | 25    | 40    | 78       | 3228   |
| 20-Nov-88 | 53    | 18    | 11    | 45    | 83       | 3475   |
| 21-Nov-88 | 43    | 15    | 12    | 48    | 88       | 3502   |
| 22-Nov-88 | 92    | 19    | 6     | 46    | 63       | 3116   |
| 23-Nov-88 | 73    | 21    | 9     | 44    | 93       | 4044   |
| 24-Nov-88 | 87    | 24    | 12    | 43    | 81       | 2849   |
| 25-Nov-88 | 142   | 30    | 13    | 48    | 72       | 3111   |
| 26-Nov-88 | 83    | 27    | 12    | 48    | 85       | 4858   |
| 27-Nov-88 | 44    | 20    | 9     | 50    | 63       | 2172   |
| 28-Nov-88 | 54    | 17    | 8     | 51    | 58       | 2287   |
| 29-Nov-88 | 61    | 16    | 2     | 44    | 55       | 2141   |
| 30-Nov-88 | 52    | 11    | 4     | 38    | 82       | 4346   |
| 01-Dec-88 | 59    | 10    | 5     | 32    | 91       | 3378   |
| 02-Dec-88 | 63    | 9     | 5     | 28    | 52       | 2195   |
| 03-Dec-88 | 65    | 21    | 8     | 26    | 59       | 2552   |
| 04-Dec-88 | 65    | 31    | 10    | 32    | 62       | 1812   |
| 05-Dec-88 | 59    | 24    | 11    | 35    | 63       | 2475   |
| 06-Dec-88 | 68    | 15    | 8     | 32    | 63       | 1814   |
| 07-Dec-88 | 51    | 19    | 10    | 34    | 84       | 3695   |
| 08-Dec-88 | 62    | 19    | 8     | 41    | 35       | 1322   |

| DATE      | LOST2 | LOST3 | LOST4 | LOST5 | AP LOADS | AP CPU |
|-----------|-------|-------|-------|-------|----------|--------|
| 09-Dec-88 | 52    | 31    | 11    | 52    | 44       | 933    |
| 10-Dec-88 | 55    | 21    | 16    | 53    | 56       | 3110   |
| 11-Dec-88 | 91    | 32    | 15    | 60    | 76       | 2512   |
| 12-Dec-88 | 85    | 39    | 21    | 72    | 30       | 2912   |
| 13-Dec-88 | 75    | 31    | 32    | 83    | 44       | 3109   |
| 14-Dec-88 | 119   | 44    | 27    | 107   | 46       | 2060   |
| 15-Dec-88 | 113   | 49    | 22    | 126   | 58       | 2974   |
| 16-Dec-88 | 98    | 76    | 40    | 140   | 72       | 2661   |
| 17-Dec-88 | 61    | 25    | 30    | 146   | 106      | 2938   |
| 18-Dec-88 | 93    | 17    | 7     | 96    | 77       | 3722   |
| 19-Dec-88 | 96    | 43    | 8     | 90    | 95       | 3935   |
| 20-Dec-88 | 112   | 61    | 25    | 77    | 41       | 2561   |
| 21-Dec-88 | 93    | 37    | 20    | 76    | 65       | 2979   |
| 22-Dec-88 | 112   | 53    | 22    | 72    | 55       | 1646   |
| 23-Dec-88 | 125   | 49    | 33    | 85    | 93       | 5667   |
| 24-Dec-88 | 60    | 61    | 27    | 98    | 61       | 4872   |
| 25-Dec-88 | 87    | 19    | 24    | 97    | 55       | 2612   |
| 26-Dec-88 | 56    | 24    | 5     | 74    | 51       | 1712   |
| 27-Dec-88 | 53    | 26    | 14    | 62    | 63       | 2268   |
| 28-Dec-88 | 72    | 14    | 13    | 60    | 81       | 2282   |
| 29-Dec-88 | 66    | 29    | 8     | 68    | 61       | 2251   |
| 30-Dec-88 | 65    | 23    | 15    | 74    | 45       | 1741   |
| 31-Dec-88 | 69    | 20    | 12    | 78    | 39       | 1244   |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL   | PAR   |
|-----------|---------|---------|--------|--------|-------|-------|
| 01-Jan-88 | 99      | 104     | 13     | 7      | 7152  | 6386  |
| 02-Jan-88 | 99      | 97      | 89     | 45     |       | 9790  |
| 03-Jan-88 | 99      | 105     | 19     | 12     | 6690  | 10089 |
| 04-Jan-88 | 99      | 102     | 67     | 18     | 9814  | 8483  |
| 05-Jan-88 | 99      | 103     | 28     | 20     | 6767  | 8929  |
| 06-Jan-88 | 99      | 105     | 112    | 37     | 12421 | 7464  |
| 07-Jan-88 | 99      | 106     | 76     | 26     | 12085 | 9943  |
| 08-Jan-88 | 99      | 109     | 39     | 24     | 9641  | 9928  |
| 09-Jan-88 | 100     | 111     | 14     | 9      | 10204 | 10467 |
| 10-Jan-88 | 100     | 104     | 9      | 7      | 4156  | 4942  |
| 11-Jan-88 | 100     | 108     | 36     | 15     | 11290 | 6852  |
| 12-Jan-88 | 100     | 114     | 58     | 23     | 9696  | 8100  |
| 13-Jan-88 | 100     | 117     | 22     | 10     | 10132 | 8477  |
| 14-Jan-88 | 100     | 118     | 171    | 57     | 7571  | 7782  |
| 15-Jan-88 | 100     | 122     | 181    | 86     | 13087 | 8966  |
| 16-Jan-88 | 100     | 127     | 17     | 10     | 9999  | 9450  |
| 17-Jan-88 | 100     | 120     | 16     | 10     | 10279 | 10080 |
| 18-Jan-88 | 100     | 115     | 34     | 14     | 11392 | 8209  |
| 19-Jan-88 | 101     | 118     | 37     | 16     | 6831  | 7275  |
| 20-Jan-88 | 101     | 116     | 16     | 12     | 788   | 8591  |
| 21-Jan-88 | 101     | 115     | 18     | 11     | 13473 | 9024  |
| 22-Jan-88 | 102     | 108     | 18     | 10     | 10511 | 8688  |
| 23-Jan-88 | 102     | 108     | 9      | 7      | 11611 | 8674  |
| 24-Jan-88 | 102     | 106     | 11     | 8      | 10661 | 8201  |
| 25-Jan-88 | 102     | 98      | 14     | 10     | 12251 | 8332  |
| 26-Jan-88 | 102     | 97      | 24     | 13     | 9412  | 8066  |
| 27-Jan-88 | 102     | 105     | 33     | 19     | 10760 | 7634  |
| 28-Jan-88 | 102     | 106     | 18     | 11     | 11003 | 7890  |
| 29-Jan-88 | 102     | 102     | 10     | 7      | 8489  | 6247  |
| 30-Jan-88 | 102     | 103     | 9      | 7      | 8211  | 8215  |
| 31-Jan-88 | 102     | 106     | 9      | 7      | 7377  | 9054  |
| 01-Feb-88 | 102     | 109     | 10     | 7      | 9061  | 10494 |
| 02-Feb-88 | 102     | 107     | 15     | 9      | 6528  | 12193 |
| 03-Feb-88 | 102     | 107     | 13     | 7      | 10488 | 11887 |
| 04-Feb-88 | 102     | 106     | 20     | 9      | 346   | 959   |
| 05-Feb-88 | 102     | 106     | 92     | 45     | 7051  | 4637  |
| 06-Feb-88 | 102     | 107     | 18     | 12     | 10438 | 11509 |
| 07-Feb-88 | 102     | 108     | 11     | 8      | 8564  | 11235 |
| 08-Feb-88 | 103     | 105     | 10     | 8      | 9260  | 10092 |
| 09-Feb-88 | 104     | 104     | 25     | 15     | 7664  | 9191  |
| 10-Feb-88 | 103     | 103     | 32     | 18     | 7852  | 7828  |
| 11-Feb-88 | 103     | 102     | 25     | 14     | 7828  | 9676  |
| 12-Feb-88 | 103     | 104     | 46     | 22     | 8691  | 8227  |
| 13-Feb-88 | 103     | 106     | 34     | 19     | 10598 | 8947  |
| 14-Feb-88 | 103     | 105     | 17     | 10     | 8320  | 10598 |
| 15-Feb-88 | 103     | 103     | 56     | 26     | 10140 | 10525 |
| 16-Feb-88 | 103     | 104     | 40     | 21     | 9620  | 9760  |
| 17-Feb-88 | 103     | 109     | 31     | 18     | 7550  | 8833  |
| 18-Feb-88 | 103     | 115     | 49     | 22     | 8018  | 8783  |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL   | PAR   |
|-----------|---------|---------|--------|--------|-------|-------|
| 19-Feb-88 | 103     | 112     | 13     | 9      | 9241  | 8463  |
| 20-Feb-88 | 103     | 109     | 12     | 8      | 10484 | 9435  |
| 21-Feb-88 | 103     | 107     | 61     | 35     | 10543 | 9483  |
| 22-Feb-88 | 103     | 105     | 155    | 123    | 11076 | 8474  |
| 23-Feb-88 | 103     | 102     | 100    | 48     | 8838  | 9032  |
| 24-Feb-88 | 103     | 102     | 30     | 17     | 11030 | 9435  |
| 25-Feb-88 | 103     | 98      | 20     | 16     | 9016  | 8630  |
| 26-Feb-88 | 103     | 99      | 22     | 15     | 8461  | 9172  |
| 27-Feb-88 | 103     | 98      | 20     | 11     | 9869  | 11012 |
| 28-Feb-88 | 103     | 99      | 14     | 9      | 9053  | 11060 |
| 29-Feb-88 | 103     | 105     | 11     | 7      | 7477  | 9212  |
| 01-Mar-88 | 103     | 103     | 14     | 9      | 6391  | 9336  |
| 02-Mar-88 | 103     | 101     | 17     | 11     | 9683  | 9109  |
| 03-Mar-88 | 104     | 103     | 17     | 13     | 7830  | 8589  |
| 04-Mar-88 | 104     | 110     | 65     | 34     | 9248  | 8750  |
| 05-Mar-88 | 104     | 110     | 13     | 11     | 9311  | 9473  |
| 06-Mar-88 | 104     | 109     | 60     | 31     | 8526  | 9472  |
| 07-Mar-88 | 104     | 109     | 32     | 19     | 9616  | 8651  |
| 08-Mar-88 | 105     | 107     | 73     | 36     | 8099  | 8564  |
| 09-Mar-88 | 105     | 103     | 33     | 19     | 9437  | 8461  |
| 10-Mar-88 | 105     | 101     | 31     | 17     | 6160  | 9054  |
| 11-Mar-88 | 105     | 104     | 37     | 19     | 121   | 8538  |
| 12-Mar-88 | 105     | 105     | 16     | 12     | 4554  | 9621  |
| 13-Mar-88 | 105     | 109     | 11     | 8      | 4470  | 9173  |
| 14-Mar-88 | 105     | 112     | 26     | 18     | 9725  | 8361  |
| 15-Mar-88 | 105     | 119     | 40     | 25     | 7876  | 8396  |
| 16-Mar-88 | 106     | 121     | 45     | 23     | 7656  | 7943  |
| 17-Mar-88 | 106     | 121     | 23     | 14     | 5576  | 6642  |
| 18-Mar-88 | 106     | 117     | 17     | 12     | 7858  | 5632  |
| 19-Mar-88 | 108     | 118     | 14     | 11     | 9587  | 9358  |
| 20-Mar-88 | 107     | 115     | 22     | 11     | 7803  | 8887  |
| 21-Mar-88 | 107     | 119     | 13     | 9      | 9077  | 9015  |
| 22-Mar-88 | 108     | 118     | 14     | 10     | 4943  | 7650  |
| 23-Mar-88 | 108     | 122     | 18     | 11     | 8561  | 8259  |
| 24-Mar-88 | 108     | 122     | 14     | 10     | 5847  | 8270  |
| 25-Mar-88 | 108     | 129     | 30     | 17     | 8520  | 7669  |
| 26-Mar-88 | 108     | 129     | 146    | 61     | 8978  | 8824  |
| 27-Mar-88 | 109     | 131     | 102    | 48     | 8028  | 8768  |
| 28-Mar-88 | 109     | 130     | 82     | 46     | 8800  | 8955  |
| 29-Mar-88 | 109     | 132     | 105    | 56     | 7053  | 8702  |
| 30-Mar-88 | 110     | 129     | 127    | 48     | 7849  | 9288  |
| 31-Mar-88 | 110     | 134     | 36     | 21     | 8772  | 9824  |
| 01-Apr-88 | 110     | 127     | 37     | 26     | 8321  | 9117  |
| 02-Apr-88 | 111     | 127     | 62     | 33     | 9320  | 10276 |
| 03-Apr-88 | 111     | 128     | 187    | 67     | 9169  | 9825  |
| 04-Apr-88 | 111     | 123     | 198    | 103    | 8710  | 7861  |
| 05-Apr-88 | 111     | 114     | 95     | 41     | 7975  | 7749  |
| 06-Apr-88 | 111     | 117     | 135    | 70     | 9193  | 9338  |
| 07-Apr-88 | 112     | 120     | 40     | 22     | 8233  | 8329  |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL  | PAR  |
|-----------|---------|---------|--------|--------|------|------|
| 08-Apr-88 | 112     | 125     | 30     | 17     | 9426 | 9169 |
| 09-Apr-88 | 112     | 127     | 36     | 18     | 9163 | 9370 |
| 10-Apr-88 | 112     | 127     | 44     | 21     | 6683 | 8764 |
| 11-Apr-88 | 112     | 131     | 24     | 15     | 8633 | 8512 |
| 12-Apr-88 | 113     | 136     | 36     | 21     | 7330 | 7751 |
| 13-Apr-88 | 113     | 134     | 27     | 17     | 7661 | 7580 |
| 14-Apr-88 | 113     | 145     | 24     | 17     | 4953 | 7338 |
| 15-Apr-88 | 113     | 143     | 23     | 14     | 7414 | 8271 |
| 16-Apr-88 | 113     | 147     | 35     | 18     | 9057 | 8709 |
| 17-Apr-88 | 114     | 144     | 22     | 12     | 8365 | 8119 |
| 18-Apr-88 | 114     | 144     | 18     | 15     | 8113 | 7278 |
| 19-Apr-88 | 114     | 137     | 19     | 15     | 7241 | 7320 |
| 20-Apr-88 | 115     | 134     | 20     | 13     | 8624 | 7133 |
| 21-Apr-88 | 115     | 126     | 28     | 15     | 5017 | 7580 |
| 22-Apr-88 | 115     | 119     | 177    | 78     | 6280 | 7714 |
| 23-Apr-88 | 115     | 110     | 91     | 33     | 9032 | 8748 |
| 24-Apr-88 | 115     | 104     | 15     | 12     | 8276 | 8429 |
| 25-Apr-88 | 115     | 105     | 18     | 14     | 8630 | 8160 |
| 26-Apr-88 | 115     | 105     | 26     | 15     | 7884 | 9154 |
| 27-Apr-88 | 115     | 103     | 23     | 15     | 8205 | 7963 |
| 28-Apr-88 | 115     | 101     | 38     | 23     | 8454 | 9011 |
| 29-Apr-88 | 115     | 100     | 20     | 14     | 704  | 8040 |
| 30-Apr-88 | 115     | 101     | 20     | 15     | 9543 | 7975 |
| 01-May-88 | 115     | 103     | 18     | 12     | 5989 | 8653 |
| 02-May-88 | 115     | 107     | 22     | 14     | 8666 | 8249 |
| 03-May-88 | 115     | 121     | 22     | 15     | 6064 | 7852 |
| 04-May-88 | 115     | 125     | 46     | 26     | 7430 | 7206 |
| 05-May-88 | 115     | 119     | 85     | 32     | 8666 | 7433 |
| 06-May-88 | 116     | 114     | 317    | 125    | 6775 | 7581 |
| 07-May-88 | 116     | 111     | 30     | 21     | 8330 | 9375 |
| 08-May-88 | 116     | 115     | 42     | 24     | 8563 | 9693 |
| 09-May-88 | 116     | 120     | 37     | 20     | 6997 | 9241 |
| 10-May-88 | 116     | 114     | 27     | 20     | 5970 | 8752 |
| 11-May-88 | 116     | 112     | 20     | 14     | 7159 | 6070 |
| 12-May-88 | 116     | 109     | 17     | 13     | 6050 |      |
| 13-May-88 | 116     | 104     | 18     | 12     | 9461 | 7158 |
| 14-May-88 | 116     | 103     | 17     | 11     | 8798 | 9935 |
| 15-May-88 | 116     | 101     | 25     | 13     | 8378 | 9752 |
| 16-May-88 | 116     | 101     | 38     | 22     | 9271 | 8824 |
| 17-May-88 | 116     | 101     | 71     | 41     | 8503 | 7778 |
| 18-May-88 | 116     | 104     | 77     | 38     | 7459 | 8127 |
| 19-May-88 | 116     | 102     | 29     | 18     | 6777 | 8626 |
| 20-May-88 | 116     | 104     | 19     | 15     | 8503 | 9385 |
| 21-May-88 | 116     | 110     | 33     | 22     | 8897 | 9108 |
| 22-May-88 | 116     | 111     | 26     | 18     | 3575 | 9543 |
| 23-May-88 | 116     | 119     | 30     | 16     | 5067 | 8983 |
| 24-May-88 | 116     | 117     | 34     | 17     | 7607 | 8154 |
| 25-May-88 | 116     | 119     | 24     | 15     | 6107 | 8891 |
| 26-May-88 | 117     | 125     | 42     | 16     | 4590 | 9903 |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL   | PAR  |
|-----------|---------|---------|--------|--------|-------|------|
| 27-May-88 | 117     | 127     | 15     | 10     | 7870  | 8779 |
| 28-May-88 | 117     | 127     | 20     | 12     | 9652  | 8935 |
| 29-May-88 | 118     | 136     | 26     | 16     | 8569  | 9003 |
| 30-May-88 | 118     | 139     | 29     | 21     | 9017  | 9116 |
| 31-May-88 | 119     | 145     | 25     | 16     | 7144  | 9082 |
| 01-Jun-88 | 119     | 150     | 20     | 14     | 8480  | 7311 |
| 02-Jun-88 | 119     | 144     | 20     | 13     | 8620  | 9654 |
| 03-Jun-88 | 120     | 145     | 18     | 11     | 8806  | 8447 |
| 04-Jun-88 | 120     | 147     | 21     | 13     | 9231  | 9910 |
| 05-Jun-88 | 121     | 147     | 33     | 19     | 9171  | 9345 |
| 06-Jun-88 | 121     | 154     | 49     | 19     | 8782  | 8493 |
| 07-Jun-88 | 122     | 160     | 24     | 14     | 7569  | 7892 |
| 08-Jun-88 | 122     | 163     | 24     | 15     | 8498  | 8036 |
| 09-Jun-88 | 123     | 165     | 28     | 15     | 10590 | 9094 |
| 10-Jun-88 | 124     | 145     | 24     | 16     | 6337  | 8743 |
| 11-Jun-88 | 124     | 134     | 21     | 16     | 8081  | 9041 |
| 12-Jun-88 | 124     | 122     | 13     | 10     | 8336  | 8904 |
| 13-Jun-88 | 124     | 112     | 20     | 13     | 10500 | 7036 |
| 14-Jun-88 | 124     | 108     | 47     | 37     | 8287  | 7934 |
| 15-Jun-88 | 124     | 111     | 25     | 18     | 9245  | 8421 |
| 16-Jun-88 | 124     | 118     | 20     | 14     | 1429  | 3375 |
| 17-Jun-88 | 124     | 121     | 34     | 21     | 5732  | 4837 |
| 18-Jun-88 | 124     | 122     | 34     | 21     | 9280  | 9441 |
| 19-Jun-88 | 124     | 116     | 67     | 33     | 6788  | 8530 |
| 20-Jun-88 | 124     | 115     | 73     | 35     | 7833  | 8959 |
| 21-Jun-88 | 124     | 121     | 38     | 16     | 9273  | 7567 |
| 22-Jun-88 | 124     | 119     | 33     | 22     | 7578  | 9757 |
| 23-Jun-88 | 124     | 125     | 22     | 17     | 8073  | 8647 |
| 24-Jun-88 | 124     | 135     | 46     | 31     | 8385  | 8648 |
| 25-Jun-88 | 124     | 150     | 83     | 48     | 8892  | 9759 |
| 26-Jun-88 | 124     | 155     | 59     | 29     | 7139  | 9355 |
| 27-Jun-88 | 124     | 155     | 48     | 21     | 9361  | 8249 |
| 28-Jun-88 | 125     | 178     | 49     | 22     | 4636  | 8007 |
| 29-Jun-88 | 126     | 183     | 75     | 45     | 7297  | 3396 |
| 30-Jun-88 | 126     | 184     | 94     | 49     | 6513  | 8982 |
| 01-Jul-88 | 127     | 193     | 56     | 31     | 9576  | 9090 |
| 02-Jul-88 | 128     | 192     | 56     | 26     | 8906  | 9100 |
| 03-Jul-88 | 128     | 187     | 27     | 18     | 5580  | 9155 |
| 04-Jul-88 | 129     | 175     | 22     | 15     | 8443  | 8929 |
| 05-Jul-88 | 130     | 166     | 25     | 14     | 7351  | 7444 |
| 06-Jul-88 | 130     | 152     | 31     | 23     | 6643  | 8163 |
| 07-Jul-88 | 130     | 147     | 31     | 20     | 7478  | 8755 |
| 08-Jul-88 | 130     | 138     | 37     | 22     | 9250  | 8100 |
| 09-Jul-88 | 130     | 133     | 16     | 12     | 9489  | 9216 |
| 10-Jul-88 | 130     | 134     | 29     | 16     | 5403  | 5135 |
| 11-Jul-88 | 130     | 137     | 53     | 36     | 10497 | 8236 |
| 12-Jul-88 | 130     | 133     | 40     | 30     | 7876  | 8699 |
| 13-Jul-88 | 130     | 138     | 19     | 14     | 10537 | 8552 |
| 14-Jul-88 | 130     | 145     | 25     | 18     | 6738  | 9028 |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL   | PAR  |
|-----------|---------|---------|--------|--------|-------|------|
| 15-Jul-88 | 130     | 146     | 32     | 22     | 9410  | 8313 |
| 16-Jul-88 | 130     | 149     | 83     | 42     | 8557  | 8542 |
| 17-Jul-88 | 131     | 157     | 29     | 17     | 8643  | 8476 |
| 18-Jul-88 | 131     | 148     | 53     | 24     | 9069  | 8438 |
| 19-Jul-88 | 131     | 138     | 43     | 20     | 8223  | 8221 |
| 20-Jul-88 | 131     | 137     | 18     | 13     | 9163  | 8576 |
| 21-Jul-88 | 131     | 141     | 245    | 65     | 6983  | 8826 |
| 22-Jul-88 | 131     | 137     | 91     | 48     | 8194  | 8342 |
| 23-Jul-88 | 132     | 140     | 72     | 32     | 8560  | 9069 |
| 24-Jul-88 | 132     | 134     | 23     | 16     | 8474  | 9109 |
| 25-Jul-88 | 132     | 137     | 24     | 14     | 10178 | 8754 |
| 26-Jul-88 | 133     | 145     | 61     | 38     | 10625 | 8282 |
| 27-Jul-88 | 134     | 157     | 47     | 27     | 9625  | 8726 |
| 28-Jul-88 | 134     | 170     | 31     | 20     | 8028  | 8985 |
| 29-Jul-88 | 135     | 180     | 27     | 17     | 10453 | 8528 |
| 30-Jul-88 | 136     | 183     | 27     | 18     | 9664  | 9344 |
| 31-Jul-88 | 137     | 187     | 26     | 19     | 8420  | 9007 |
| 01-Aug-88 | 137     | 176     | 41     | 21     | 9822  | 9467 |
| 02-Aug-88 | 138     | 182     | 25     | 17     | 7543  | 9221 |
| 03-Aug-88 | 139     | 173     | 33     | 18     | 6074  | 7925 |
| 04-Aug-88 | 139     | 159     | 23     | 11     | 9038  | 7671 |
| 05-Aug-88 | 140     | 155     | 27     | 20     | 9848  | 8553 |
| 06-Aug-88 | 140     | 160     | 20     | 14     | 9241  | 8443 |
| 07-Aug-88 | 141     | 166     | 20     | 13     | 8487  | 8070 |
| 08-Aug-88 | 141     | 181     | 19     | 13     | 9232  | 7804 |
| 09-Aug-88 | 142     | 180     | 116    | 40     | 7401  | 9834 |
| 10-Aug-88 | 143     | 180     | 29     | 17     | 8993  | 6652 |
| 11-Aug-88 | 144     | 173     | 24     | 16     | 5750  | 6990 |
| 12-Aug-88 | 144     | 158     | 33     | 24     | 1666  | 7643 |
| 13-Aug-88 | 145     | 157     | 44     | 30     | 9868  | 8167 |
| 14-Aug-88 | 146     | 149     | 51     | 34     | 6793  | 7844 |
| 15-Aug-88 | 146     | 140     | 65     | 30     | 7381  | 8222 |
| 16-Aug-88 | 146     | 135     | 31     | 17     | 8593  | 7529 |
| 17-Aug-88 | 147     | 138     | 16     | 12     | 10052 | 8180 |
| 18-Aug-88 | 147     | 125     | 48     | 20     | 7801  | 8206 |
| 19-Aug-88 | 147     | 121     | 25     | 15     | 9638  | 8737 |
| 20-Aug-88 | 147     | 115     | 48     | 27     | 8873  | 8891 |
| 21-Aug-88 | 147     | 113     | 30     | 13     | 8940  | 8689 |
| 22-Aug-88 | 147     | 113     | 105    | 38     | 10119 | 8497 |
| 23-Aug-88 | 147     | 120     | 34     | 21     | 9603  | 9048 |
| 24-Aug-88 | 147     | 131     | 20     | 15     | 8725  | 8228 |
| 25-Aug-88 | 147     | 140     | 33     | 24     | 7006  | 7469 |
| 26-Aug-88 | 147     | 153     | 32     | 17     | 9286  | 7843 |
| 27-Aug-88 | 148     | 163     | 45     | 29     | 9520  | 8436 |
| 28-Aug-88 | 148     | 171     | 35     | 18     | 8505  | 8553 |
| 29-Aug-88 | 149     | 185     | 44     | 29     | 10317 | 8150 |
| 30-Aug-88 | 149     | 187     | 66     | 31     | 10062 | 7978 |
| 31-Aug-88 | 150     | 190     | 39     | 26     | 8854  | 8580 |
| 01-Sep-88 | 150     | 189     | 91     | 39     | 8764  | 8636 |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL   | PAR   |
|-----------|---------|---------|--------|--------|-------|-------|
| 02-Sep-88 | 150     | 176     | 53     | 26     | 10123 | 8012  |
| 03-Sep-88 | 151     | 174     | 42     | 19     | 10065 | 8955  |
| 04-Sep-88 | 151     | 163     | 23     | 15     | 7808  | 7317  |
| 05-Sep-88 | 151     | 163     | 13     | 10     | 9697  | 6954  |
| 06-Sep-88 | 151     | 150     | 14     | 10     | 10552 | 8006  |
| 07-Sep-88 | 150     | 143     | 16     | 11     | 9963  | 8386  |
| 08-Sep-88 | 150     | 136     | 18     | 12     | 10216 | 8651  |
| 09-Sep-88 | 150     | 126     | 16     | 11     | 10705 | 8274  |
| 10-Sep-88 | 150     | 114     | 38     | 17     | 11094 | 8562  |
| 11-Sep-88 | 150     | 120     | 121    | 65     | 11180 | 8367  |
| 12-Sep-88 | 150     | 124     | 100    | 36     | 7775  | 6933  |
| 13-Sep-88 | 150     | 122     | 49     | 24     | 11054 | 12322 |
| 14-Sep-88 | 151     | 129     | 34     | 19     | 10948 | 0913  |
| 15-Sep-88 | 151     | 125     | 27     | 19     | 9120  | 12657 |
| 16-Sep-88 | 151     | 127     | 27     | 13     | 10512 | 12086 |
| 17-Sep-88 | 151     | 133     | 50     | 34     | 10355 | 12313 |
| 18-Sep-88 | 151     | 139     | 99     | 51     | 7983  | 12204 |
| 19-Sep-88 | 151     | 138     | 75     | 43     | 9381  | 11280 |
| 20-Sep-88 | 152     | 149     | 24     | 18     | 8072  | 12142 |
| 21-Sep-88 | 152     | 156     | 24     | 15     | 5369  | 12479 |
| 22-Sep-88 | 153     | 178     | 49     | 29     | 492   | 8525  |
| 23-Sep-88 | 153     | 180     | 31     | 19     | 17010 | 8579  |
| 24-Sep-88 | 153     | 179     | 18     | 13     | 9086  | 8386  |
| 25-Sep-88 | 153     | 177     | 53     | 19     | 8090  | 8528  |
| 26-Sep-88 | 153     | 173     | 17     | 11     | 9304  | 8141  |
| 27-Sep-88 | 153     | 173     | 15     | 11     | 7488  | 8476  |
| 28-Sep-88 | 153     | 171     | 16     | 11     | 8720  | 8342  |
| 29-Sep-88 | 153     | 173     | 13     | 10     | 7824  | 7836  |
| 30-Sep-88 | 153     | 172     | 18     | 13     | 10104 | 8307  |
| 01-Oct-88 | 152     | 179     | 25     | 17     | 5556  | 9336  |
| 02-Oct-88 | 153     | 195     | 12     | 9      | 7654  | 8551  |
| 03-Oct-88 | 153     | 202     | 15     | 10     | 9913  | 9297  |
| 04-Oct-88 | 154     | 189     | 39     | 15     | 7881  | 8728  |
| 05-Oct-88 | 154     | 189     | 41     | 24     | 9861  | 8387  |
| 06-Oct-88 | 155     | 188     | 75     | 40     | 8058  | 9086  |
| 07-Oct-88 | 155     | 181     | 22     | 13     | 12635 | 8868  |
| 08-Oct-88 | 156     | 174     | 23     | 13     | 10928 | 8907  |
| 09-Oct-88 | 156     | 176     | 33     | 22     | 10423 | 9417  |
| 10-Oct-88 | 156     | 179     | 193    | 103    | 10902 | 8896  |
| 11-Oct-88 | 157     | 170     | 72     | 27     | 7510  | 6929  |
| 12-Oct-88 | 157     | 149     | 25     | 16     | 4727  | 5586  |
| 13-Oct-88 | 157     | 159     | 20     | 15     | 1670  | 1536  |
| 14-Oct-88 | 157     | 151     | 17     | 11     | 8003  | 4700  |
| 15-Oct-88 | 157     | 150     | 26     | 11     | 3294  | 4258  |
| 16-Oct-88 | 157     | 155     | 19     | 14     | 7854  | 9905  |
| 17-Oct-88 | 157     | 178     | 42     | 19     | 11469 | 9187  |
| 18-Oct-88 | 157     | 178     | 49     | 34     | 9961  | 8430  |
| 19-Oct-88 | 158     | 166     | 29     | 20     | 12287 | 8821  |
| 20-Oct-88 | 158     | 168     | 37     | 23     | 6184  | 8395  |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL   | PAR   |
|-----------|---------|---------|--------|--------|-------|-------|
| 21-Oct-88 | 159     | 166     | 16     | 11     | 7214  | 8818  |
| 22-Oct-88 | 159     | 166     | 16     | 9      | 11245 | 9214  |
| 23-Oct-88 | 159     | 171     | 17     | 10     | 9845  | 9870  |
| 24-Oct-88 | 160     | 170     | 13     | 10     | 11593 | 10132 |
| 25-Oct-88 | 160     | 164     | 14     | 8      | 11450 | 9165  |
| 26-Oct-88 | 160     | 157     | 17     | 11     | 8274  | 7043  |
| 27-Oct-88 | 159     | 163     | 19     | 12     | 10123 | 7621  |
| 28-Oct-88 | 159     | 158     | 18     | 13     | 11979 | 7530  |
| 29-Oct-88 | 159     | 156     | 19     | 9      | 11675 | 8217  |
| 30-Oct-88 | 159     | 167     | 20     | 9      | 11004 | 8333  |
| 31-Oct-88 | 158     | 161     | 29     | 15     | 11692 | 8203  |
| 01-Nov-88 | 158     | 157     | 15     | 11     | 6483  | 1386  |
| 02-Nov-88 | 158     | 167     | 38     | 24     | 5936  | 7413  |
| 03-Nov-88 | 159     | 167     | 37     | 25     | 8149  | 8902  |
| 04-Nov-88 | 159     | 162     | 15     | 9      | 11299 | 7791  |
| 05-Nov-88 | 159     | 169     | 20     | 12     | 10326 | 9341  |
| 06-Nov-88 | 158     | 165     | 25     | 14     | 10687 | 9266  |
| 07-Nov-88 | 158     | 155     | 24     | 17     | 11392 | 8328  |
| 08-Nov-88 | 158     | 146     | 32     | 19     | 10696 | 7300  |
| 09-Nov-88 | 158     | 156     | 23     | 13     | 14206 | 9913  |
| 10-Nov-88 | 157     | 152     | 31     | 16     | 9963  | 7991  |
| 11-Nov-88 | 157     | 157     | 16     | 9      | 12686 | 7565  |
| 12-Nov-88 | 158     | 156     | 32     | 15     | 12904 | 8173  |
| 13-Nov-88 | 158     | 171     | 13     | 9      | 13081 | 8044  |
| 14-Nov-88 | 158     | 179     | 19     | 11     | 13096 | 7525  |
| 15-Nov-88 | 159     | 174     | 14     | 10     | 9110  | 7522  |
| 16-Nov-88 | 160     | 189     | 29     | 18     | 3538  | 7421  |
| 17-Nov-88 | 160     | 180     | 20     | 13     | 7806  | 7557  |
| 18-Nov-88 | 161     | 166     | 11     | 8      | 5999  | 7524  |
| 19-Nov-88 | 161     | 156     | 5      | 4      | 11008 | 7817  |
| 20-Nov-88 | 162     | 147     | 7      | 3      | 8800  | 7929  |
| 21-Nov-88 | 162     | 157     | 7      | 6      | 11533 | 7964  |
| 22-Nov-88 | 162     | 150     | 9      | 6      | 10871 | 8356  |
| 23-Nov-88 | 162     | 139     | 7      | 5      | 7454  | 7315  |
| 24-Nov-88 | 162     | 142     | 7      | 5      | 1010  | 8218  |
| 25-Nov-88 | 162     | 143     | 13     | 7      | 11114 | 8019  |
| 26-Nov-88 | 162     | 142     | 27     | 18     | 10820 | 7882  |
| 27-Nov-88 | 161     | 145     | 21     | 11     | 10104 | 7571  |
| 28-Nov-88 | 161     | 142     | 26     | 10     | 9487  | 7340  |
| 29-Nov-88 | 160     | 143     | 13     | 9      | 9573  | 7164  |
| 30-Nov-88 | 160     | 140     | 63     | 29     | 11444 | 7219  |
| 01-Dec-88 | 159     | 155     | 25     | 10     | 11137 | 7093  |
| 02-Dec-88 | 159     | 154     | 40     | 17     | 14137 | 7768  |
| 03-Dec-88 | 159     | 151     | 34     | 18     | 12854 | 7916  |
| 04-Dec-88 | 159     | 146     | 14     | 11     | 12979 | 7795  |
| 05-Dec-88 | 159     | 163     | 9      | 6      | 11589 | 7689  |
| 06-Dec-88 | 159     | 157     | 9      | 6      | 11777 | 7239  |
| 07-Dec-88 | 159     | 165     | 9      | 6      | 2970  | 7063  |
| 08-Dec-88 | 160     | 169     | 11     | 6      | 1242  | 6706  |

| DATE      | F10 BAR | F10 ACT | AP MAX | AP AVG | EGL   | PAR  |
|-----------|---------|---------|--------|--------|-------|------|
| 09-Dec-88 | 161     | 170     | 10     | 6      | 12167 | 7411 |
| 10-Dec-88 | 161     | 164     | 20     | 11     | 9236  | 6719 |
| 11-Dec-88 | 162     | 184     | 33     | 15     | 9631  | 7636 |
| 12-Dec-88 | 162     | 180     | 35     | 12     | 11554 | 7132 |
| 13-Dec-88 | 163     | 186     | 35     | 20     | 11236 | 8431 |
| 14-Dec-88 | 164     | 215     | 38     | 13     | 12111 | 8954 |
| 15-Dec-88 | 165     | 219     | 20     | 10     | 11564 | 8738 |
| 16-Dec-88 | 166     | 239     | 37     | 21     | 12625 | 9490 |
| 17-Dec-88 | 167     | 250     | 65     | 33     | 12537 | 9089 |
| 18-Dec-88 | 169     | 253     | 48     | 23     | 13419 | 8816 |
| 19-Dec-88 | 170     | 249     | 34     | 20     | 13200 | 8424 |
| 20-Dec-88 | 171     | 252     | 9      | 7      | 11023 | 9003 |
| 21-Dec-88 | 172     | 252     | 21     | 12     | 9722  | 6369 |
| 22-Dec-88 | 173     | 255     | 14     | 11     | 13672 | 7883 |
| 23-Dec-88 | 173     | 245     | 9      | 7      | 13128 | 8673 |
| 24-Dec-88 | 174     | 229     | 10     | 6      | 14020 | 8194 |
| 25-Dec-88 | 174     | 220     | 38     | 20     | 13168 | 7731 |
| 26-Dec-88 | 175     | 201     | 37     | 23     | 14335 | 7767 |
| 27-Dec-88 | 175     | 212     | 31     | 20     | 12393 | 7783 |
| 28-Dec-88 | 176     | 209     | 26     | 15     | 11304 | 7268 |
| 29-Dec-88 | 176     | 202     | 30     | 19     | 14450 | 7484 |
| 30-Dec-88 | 176     | 180     | 27     | 12     | 14385 | 6707 |
| 31-Dec-88 | 176     | 182     | 19     | 12     | 12991 | 7399 |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 01-Jan-88 | 1773 | 1019 | 1408 | 885  | 1458 |
| 02-Jan-88 | 2614 | 1551 | 2259 | 1147 | 2524 |
| 03-Jan-88 | 2559 | 1669 | 2509 | 1182 | 2688 |
| 04-Jan-88 | 3119 | 1297 | 1804 | 1089 | 2339 |
| 05-Jan-88 | 2555 | 1547 | 1733 | 1132 | 2579 |
| 06-Jan-88 | 2489 | 2174 | 2451 | 890  | 2541 |
| 07-Jan-88 | 2534 | 1202 | 1890 | 1761 | 2748 |
| 08-Jan-88 | 2344 | 1803 | 1721 | 1560 | 2196 |
| 09-Jan-88 | 2516 | 1439 | 1984 | 1551 | 1479 |
| 10-Jan-88 | 1795 | 803  | 1070 | 628  | 1074 |
| 11-Jan-88 | 1833 | 1563 | 2085 | 1554 | 2400 |
| 12-Jan-88 | 2853 | 1666 | 1268 | 1188 | 2331 |
| 13-Jan-88 | 2453 | 1585 | 1571 | 1370 | 2543 |
| 14-Jan-88 | 2540 | 1849 | 1624 | 1244 | 2352 |
| 15-Jan-88 | 2464 | 1868 | 1948 | 1619 | 2552 |
| 16-Jan-88 | 2557 | 2336 | 2212 | 1659 | 2641 |
| 17-Jan-88 | 2527 | 1523 | 2557 | 3130 | 2700 |
| 18-Jan-88 | 2534 | 1878 | 2353 | 1579 | 2313 |
| 19-Jan-88 | 2625 | 1673 | 1802 | 1186 | 1471 |
| 20-Jan-88 | 2660 | 1745 | 1853 | 1256 | 2499 |
| 21-Jan-88 | 2705 | 2096 | 1870 | 1320 | 2430 |
| 22-Jan-88 | 2758 | 1510 | 2027 | 1434 | 1739 |
| 23-Jan-88 | 2275 | 1937 | 2178 | 1241 | 2372 |
| 24-Jan-88 | 2540 | 1939 | 2033 | 1280 | 2434 |
| 25-Jan-88 | 1826 | 1442 | 1663 | 1278 | 1708 |
| 26-Jan-88 | 3245 | 1640 | 1865 | 1233 | 1606 |
| 27-Jan-88 | 2879 | 1722 | 2180 | 771  | 1410 |
| 28-Jan-88 | 2399 | 1442 | 2151 | 1354 | 1216 |
| 29-Jan-88 | 2445 | 1755 | 2011 | 1330 | 1679 |
| 30-Jan-88 | 2420 | 1938 | 2234 | 1399 | 2512 |
| 31-Jan-88 | 2742 | 1998 | 2532 | 1521 | 2056 |
| 01-Feb-88 | 2895 | 2057 | 2406 | 1548 | 1775 |
| 02-Feb-88 | 3437 | 2446 | 2317 | 1537 | 1149 |
| 03-Feb-88 | 2407 | 2131 | 2067 | 1245 | 1311 |
| 04-Feb-88 | 697  | 86   | 149  | 42   | 36   |
| 05-Feb-88 | 809  | 1323 | 896  | 885  | 1105 |
| 06-Feb-88 | 2966 | 1896 | 2075 | 1636 | 1636 |
| 07-Feb-88 | 2697 | 1877 | 2468 | 1614 | 1673 |
| 08-Feb-88 | 2731 | 2082 | 1822 | 1489 | 1450 |
| 09-Feb-88 | 2707 | 2171 | 1821 | 1645 | 1837 |
| 10-Feb-88 | 2745 | 1732 | 1841 | 1436 | 1369 |
| 11-Feb-88 | 2936 | 2186 | 1149 | 1578 | 1305 |
| 12-Feb-88 | 2389 | 2207 | 1856 | 1202 | 1566 |
| 13-Feb-88 | 2384 | 2164 | 2292 | 1512 | 1593 |
| 14-Feb-88 | 2818 | 1588 | 2580 | 1474 | 1600 |
| 15-Feb-88 | 2412 | 1887 | 2231 | 1454 | 1612 |
| 16-Feb-88 | 2697 | 2648 | 1878 | 1387 | 1441 |
| 17-Feb-88 | 2587 | 1817 | 2282 | 1410 | 1558 |
| 18-Feb-88 | 2463 | 1911 | 1850 | 1390 | 1960 |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 19-Feb-88 | 2474 | 2134 | 2172 | 1611 | 1770 |
| 20-Feb-88 | 2579 | 1979 | 2319 | 1593 | 1914 |
| 21-Feb-88 | 2506 | 2270 | 2427 | 1182 | 1627 |
| 22-Feb-88 | 2498 | 2260 | 2162 | 1498 | 1746 |
| 23-Feb-88 | 2411 | 1861 | 2299 | 1499 | 1766 |
| 24-Feb-88 | 2346 | 1667 | 2372 | 1067 | 2010 |
| 25-Feb-88 | 2439 | 1682 | 2747 | 1609 | 1276 |
| 26-Feb-88 | 2488 | 2042 | 1885 | 1663 | 1911 |
| 27-Feb-88 | 2587 | 1422 | 2115 | 1875 | 1871 |
| 28-Feb-88 | 2750 | 1615 | 2343 | 1455 | 1621 |
| 29-Feb-88 | 2752 | 1643 | 1093 | 1616 | 1838 |
| 01-Mar-88 | 2624 | 2233 | 1898 | 1697 | 1787 |
| 02-Mar-88 | 2743 | 1752 | 2865 | 1499 | 1944 |
| 03-Mar-88 | 2356 | 1636 | 2189 | 1414 | 1324 |
| 04-Mar-88 | 2374 | 1708 | 2912 | 1523 | 2034 |
| 05-Mar-88 | 2510 | 1754 | 1876 | 1517 | 1602 |
| 06-Mar-88 | 2454 | 1577 | 1595 | 1643 | 1716 |
| 07-Mar-88 | 2435 | 1763 | 1850 | 1449 | 1573 |
| 08-Mar-88 | 2493 | 1175 | 1597 | 1486 | 1195 |
| 09-Mar-88 | 2336 | 1632 | 1988 | 1001 | 1509 |
| 10-Mar-88 | 2383 | 1971 | 2033 | 1458 | 1844 |
| 11-Mar-88 | 2405 | 2583 | 2831 | 2487 | 2755 |
| 12-Mar-88 | 2707 | 2009 | 3044 | 3125 | 3532 |
| 13-Mar-88 | 2492 | 1784 | 1916 | 4728 | 2764 |
| 14-Mar-88 | 2556 | 1863 | 1561 | 2767 | 2656 |
| 15-Mar-88 | 2403 | 1724 | 1333 | 2573 | 2770 |
| 16-Mar-88 | 2523 | 1865 | 1675 | 2056 | 2583 |
| 17-Mar-88 | 1515 | 1498 | 1529 | 1538 | 1562 |
| 18-Mar-88 | 1569 | 1719 | 1276 | 1986 | 2190 |
| 19-Mar-88 | 2415 | 2233 | 2709 | 2746 | 2923 |
| 20-Mar-88 | 2355 | 2125 | 2342 | 2651 | 3186 |
| 21-Mar-88 | 2263 | 1615 | 1835 | 2407 | 2590 |
| 22-Mar-88 | 1781 | 1930 | 2302 | 2951 | 2425 |
| 23-Mar-88 | 2235 | 2171 | 2711 | 1959 | 2775 |
| 24-Mar-88 | 2482 | 1651 | 2823 | 1550 | 2258 |
| 25-Mar-88 | 2316 | 1746 | 2500 | 1563 | 1716 |
| 26-Mar-88 | 2251 | 2037 | 1734 | 1672 | 1857 |
| 27-Mar-88 | 2393 | 1812 | 2385 | 1540 | 1753 |
| 28-Mar-88 | 2480 | 1464 | 3019 | 3772 | 1901 |
| 29-Mar-88 | 2390 | 2395 | 2679 | 1000 | 2074 |
| 30-Mar-88 | 2469 | 2134 | 2451 | 1685 | 1926 |
| 31-Mar-88 | 2429 | 2562 | 2481 | 1914 | 1812 |
| 01-Apr-88 | 2892 | 2381 | 2571 | 1845 | 1969 |
| 02-Apr-88 | 2544 | 1830 | 2295 | 1637 | 1774 |
| 03-Apr-88 | 2460 | 2522 | 2482 | 1742 | 1778 |
| 04-Apr-88 | 2465 | 1439 | 1832 | 1700 | 2748 |
| 05-Apr-88 | 3207 | 1233 | 1112 | 1966 | 1888 |
| 06-Apr-88 | 2322 | 2226 | 2356 | 1451 | 1779 |
| 07-Apr-88 | 2386 | 3021 | 2334 | 1606 | 1615 |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 08-Apr-88 | 2477 | 1944 | 2125 | 1470 | 1511 |
| 09-Apr-88 | 2442 | 2150 | 2132 | 1279 | 1595 |
| 10-Apr-88 | 2421 | 2751 | 2388 | 3084 | 1491 |
| 11-Apr-88 | 2368 | 1822 | 2015 | 1201 | 1464 |
| 12-Apr-88 | 2342 | 1685 | 2032 | 1170 | 1058 |
| 13-Apr-88 | 2382 | 1944 | 1658 | 1067 | 1358 |
| 14-Apr-88 | 2299 | 1859 | 1695 | 1256 | 1002 |
| 15-Apr-88 | 2301 | 1819 | 1715 | 1321 | 1447 |
| 16-Apr-88 | 2545 | 1526 | 2121 | 1191 | 1373 |
| 17-Apr-88 | 2271 | 1575 | 1990 | 1367 | 1277 |
| 18-Apr-88 | 2261 | 1628 | 2238 | 1256 | 1350 |
| 19-Apr-88 | 2209 | 1324 | 2472 | 1230 | 1101 |
| 20-Apr-88 | 2234 | 1632 | 1516 | 951  | 1316 |
| 21-Apr-88 | 2254 | 2061 | 2077 | 1377 | 1558 |
| 22-Apr-88 | 2187 | 1510 | 3120 | 1154 | 1378 |
| 23-Apr-88 | 2359 | 1460 | 2901 | 1199 | 1272 |
| 24-Apr-88 | 2365 | 1594 | 3434 | 1029 | 1277 |
| 25-Apr-88 | 2168 | 1817 | 3680 | 1157 | 1259 |
| 26-Apr-88 | 2348 | 1783 | 3373 | 1081 | 1428 |
| 27-Apr-88 | 2311 | 1815 | 3415 | 1320 | 901  |
| 28-Apr-88 | 2919 | 1585 | 3729 | 1715 | 1834 |
| 29-Apr-88 | 2731 | 2114 | 3196 | 1810 | 1958 |
| 30-Apr-88 | 2474 | 2416 | 3447 | 1451 | 1537 |
| 01-May-88 | 2330 | 1440 | 2154 | 1240 | 1484 |
| 02-May-88 | 2284 | 1900 | 2941 | 1267 | 1171 |
| 03-May-88 | 2257 | 1280 | 2404 | 1373 | 1541 |
| 04-May-88 | 2241 | 1555 | 1846 | 1138 | 1025 |
| 05-May-88 | 2243 | 1489 | 2833 | 1251 | 1499 |
| 06-May-88 | 2384 | 1810 | 3371 | 1313 | 1681 |
| 07-May-88 | 2224 | 1882 | 2901 | 1259 | 1483 |
| 08-May-88 | 2436 | 1760 | 2683 | 1033 | 1548 |
| 09-May-88 | 2322 | 1315 | 2362 | 974  | 1320 |
| 10-May-88 | 2316 | 2140 | 2778 | 1203 | 1199 |
| 11-May-88 | 2434 | 1760 | 2985 | 736  | 1388 |
| 12-May-88 | 2273 | 1597 | 3169 | 1266 | 1486 |
| 13-May-88 | 2414 | 1627 | 3295 | 1552 | 1523 |
| 14-May-88 | 2124 | 1342 | 2765 | 1414 | 1495 |
| 15-May-88 | 2591 | 1753 | 2642 | 1118 | 1374 |
| 16-May-88 | 2195 | 1548 | 2345 | 1203 | 1438 |
| 17-May-88 | 2191 | 1421 | 2340 | 1327 | 1458 |
| 18-May-88 | 2153 | 1499 | 2729 | 973  | 983  |
| 19-May-88 | 2616 | 1455 | 2816 | 1281 | 1391 |
| 20-May-88 | 2200 | 1768 | 1693 | 1246 | 1460 |
| 21-May-88 | 2199 | 1257 | 1504 | 1354 | 1326 |
| 22-May-88 | 2270 | 2245 | 1778 | 1212 | 1383 |
| 23-May-88 | 2181 | 1953 | 1667 | 1258 | 1362 |
| 24-May-88 | 2210 | 1529 | 1313 | 987  | 1232 |
| 25-May-88 | 2335 | 1824 | 1616 | 1361 | 1437 |
| 26-May-88 | 2151 | 1937 | 1726 | 1267 | 925  |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 27-May-88 | 2247 | 1534 | 1715 | 1422 | 1288 |
| 28-May-88 | 2161 | 1595 | 1684 | 1443 | 1200 |
| 29-May-88 | 2117 | 1525 | 1267 | 1378 | 1320 |
| 30-May-88 | 2205 | 2007 | 1596 | 1262 | 1251 |
| 31-May-88 | 2101 | 1862 | 1738 | 1391 | 1332 |
| 01-Jun-88 | 2070 | 1705 | 1806 | 1229 | 977  |
| 02-Jun-88 | 2230 | 1872 | 1392 | 1265 | 1200 |
| 03-Jun-88 | 2219 | 1596 | 989  | 1036 | 1178 |
| 04-Jun-88 | 2184 | 1454 | 1159 | 1177 | 1306 |
| 05-Jun-88 | 2576 | 1724 | 1632 | 1121 | 1350 |
| 06-Jun-88 | 2080 | 1603 | 1266 | 1285 | 1381 |
| 07-Jun-88 | 2177 | 1943 | 1322 | 1310 | 1052 |
| 08-Jun-88 | 2536 | 1619 | 1228 | 982  | 1483 |
| 09-Jun-88 | 2450 | 1476 | 1469 | 1213 | 1421 |
| 10-Jun-88 | 2133 | 1316 | 1436 | 1227 | 1393 |
| 11-Jun-88 | 2301 | 1254 | 1498 | 1254 | 1248 |
| 12-Jun-88 | 2103 | 1084 | 1651 | 1282 | 1431 |
| 13-Jun-88 | 2219 | 1251 | 1728 | 1208 | 1423 |
| 14-Jun-88 | 2208 | 1499 | 1831 | 1300 | 1431 |
| 15-Jun-88 | 2151 | 1505 | 1814 | 1653 | 1609 |
| 16-Jun-88 | 767  | 369  | 427  | 314  | 370  |
| 17-Jun-88 | 706  | 861  | 417  | 1486 | 845  |
| 18-Jun-88 | 2400 | 1884 | 1950 | 2760 | 1479 |
| 19-Jun-88 | 2305 | 1240 | 1404 | 1978 | 1317 |
| 20-Jun-88 | 2273 | 1436 | 1953 | 2570 | 1570 |
| 21-Jun-88 | 2223 | 1535 | 1848 | 2364 | 1372 |
| 22-Jun-88 | 2281 | 1433 | 1971 | 1968 | 1095 |
| 23-Jun-88 | 2200 | 1693 | 1935 | 2464 | 1225 |
| 24-Jun-88 | 2201 | 1580 | 1751 | 1995 | 1545 |
| 25-Jun-88 | 2185 | 1611 | 1797 | 1941 | 1568 |
| 26-Jun-88 | 2268 | 1497 | 1446 | 2652 | 1531 |
| 27-Jun-88 | 2216 | 1517 | 1172 | 2098 | 1439 |
| 28-Jun-88 | 2137 | 1137 | 1564 | 1893 | 896  |
| 29-Jun-88 | 717  | 783  | 1034 | 1336 | 352  |
| 30-Jun-88 | 2121 | 1269 | 1690 | 2186 | 1390 |
| 01-Jul-88 | 2183 | 1494 | 1720 | 2348 | 1410 |
| 02-Jul-88 | 2310 | 1381 | 1652 | 2293 | 1156 |
| 03-Jul-88 | 2204 | 1473 | 1677 | 2285 | 1607 |
| 04-Jul-88 | 2133 | 1468 | 1609 | 2596 | 1520 |
| 05-Jul-88 | 1538 | 1502 | 1310 | 2419 | 1368 |
| 06-Jul-88 | 2248 | 1647 | 1896 | 1623 | 1554 |
| 07-Jul-88 | 2130 | 1675 | 1554 | 2237 | 1441 |
| 08-Jul-88 | 2140 | 1292 | 1663 | 1870 | 1347 |
| 09-Jul-88 | 2213 | 1054 | 1394 | 1942 | 1242 |
| 10-Jul-88 | 1499 | 618  | 795  | 1306 | 513  |
| 11-Jul-88 | 2255 | 920  | 1139 | 2168 | 1118 |
| 12-Jul-88 | 2135 | 1253 | 724  | 1863 | 2365 |
| 13-Jul-88 | 2166 | 1285 | 1369 | 2035 | 2241 |
| 14-Jul-88 | 2238 | 1416 | 1805 | 999  | 1815 |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 15-Jul-88 | 1914 | 1395 | 1676 | 1937 | 1315 |
| 16-Jul-88 | 2216 | 984  | 1602 | 1551 | 1318 |
| 17-Jul-88 | 2280 | 1455 | 1438 | 2082 | 1273 |
| 18-Jul-88 | 2140 | 1514 | 1668 | 2029 | 1254 |
| 19-Jul-88 | 2138 | 1494 | 1767 | 2069 | 1393 |
| 20-Jul-88 | 2086 | 1562 | 1794 | 2162 | 1375 |
| 21-Jul-88 | 2070 | 1422 | 1533 | 2510 | 1017 |
| 22-Jul-88 | 2147 | 1254 | 1466 | 1937 | 1289 |
| 23-Jul-88 | 2307 | 1321 | 1452 | 1216 | 1386 |
| 24-Jul-88 | 2380 | 1395 | 1568 | 1174 | 1400 |
| 25-Jul-88 | 2292 | 1177 | 1323 | 1232 | 1308 |
| 26-Jul-88 | 2253 | 1331 | 1358 | 1257 | 1251 |
| 27-Jul-88 | 2377 | 1465 | 1751 | 1271 | 1362 |
| 28-Jul-88 | 1691 | 856  | 1514 | 1063 | 1394 |
| 29-Jul-88 | 2209 | 1396 | 1544 | 1026 | 1199 |
| 30-Jul-88 | 2321 | 1331 | 1286 | 985  | 1242 |
| 31-Jul-88 | 2344 | 1245 | 1223 | 1075 | 1122 |
| 01-Aug-88 | 2360 | 1047 | 976  | 1088 | 1266 |
| 02-Aug-88 | 2209 | 1250 | 1298 | 1009 | 1176 |
| 03-Aug-88 | 2259 | 1414 | 1670 | 1085 | 1328 |
| 04-Aug-88 | 2290 | 1375 | 1230 | 1046 | 1524 |
| 05-Aug-88 | 2166 | 1400 | 1524 | 1061 | 1193 |
| 06-Aug-88 | 2242 | 1344 | 1461 | 1077 | 1180 |
| 07-Aug-88 | 2417 | 1407 | 1490 | 1115 | 1258 |
| 08-Aug-88 | 2246 | 1320 | 1690 | 1095 | 1381 |
| 09-Aug-88 | 2199 | 1450 | 1597 | 1222 | 1291 |
| 10-Aug-88 | 2338 | 1517 | 1602 | 1221 | 1343 |
| 11-Aug-88 | 2498 | 1437 | 1659 | 1013 | 1176 |
| 12-Aug-88 | 2471 | 1456 | 831  | 1059 | 1267 |
| 13-Aug-88 | 2322 | 1027 | 1299 | 1162 | 1361 |
| 14-Aug-88 | 2607 | 1390 | 1368 | 1136 | 1302 |
| 15-Aug-88 | 2500 | 1426 | 1310 | 1184 | 1338 |
| 16-Aug-88 | 2392 | 1530 | 1501 | 1180 | 906  |
| 17-Aug-88 | 2381 | 1430 | 1783 | 1202 | 1801 |
| 18-Aug-88 | 2372 | 1425 | 1710 | 1329 | 1570 |
| 19-Aug-88 | 2341 | 1684 | 1417 | 1738 | 1612 |
| 20-Aug-88 | 2237 | 1622 | 1467 | 1252 | 1535 |
| 21-Aug-88 | 2310 | 1518 | 1696 | 1132 | 1467 |
| 22-Aug-88 | 2282 | 1498 | 1305 | 1148 | 1312 |
| 23-Aug-88 | 2319 | 1438 | 1737 | 1286 | 1129 |
| 24-Aug-88 | 2143 | 1415 | 1565 | 1206 | 1121 |
| 25-Aug-88 | 2158 | 1541 | 1250 | 909  | 1690 |
| 26-Aug-88 | 2200 | 1334 | 1655 | 1306 | 2710 |
| 27-Aug-88 | 1971 | 1326 | 1210 | 1376 | 1518 |
| 28-Aug-88 | 2273 | 1411 | 1122 | 1245 | 1589 |
| 29-Aug-88 | 2148 | 1692 | 1276 | 1192 | 1424 |
| 30-Aug-88 | 2263 | 1660 | 1716 | 1272 | 1287 |
| 31-Aug-88 | 2520 | 1238 | 1321 | 1120 | 1305 |
| 01-Sep-88 | 2189 | 1488 | 1516 | 991  | 1287 |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 02-Sep-88 | 2254 | 1250 | 1214 | 1149 | 1482 |
| 03-Sep-88 | 2391 | 1290 | 1671 | 1273 | 1510 |
| 04-Sep-88 | 2290 | 1334 | 1507 | 1245 | 1397 |
| 05-Sep-88 | 2260 | 1440 | 1872 | 1358 | 1657 |
| 06-Sep-88 | 2342 | 1534 | 1509 | 1311 | 1511 |
| 07-Sep-88 | 2295 | 1998 | 1450 | 1440 | 1708 |
| 08-Sep-88 | 2330 | 1758 | 1888 | 1119 | 1850 |
| 09-Sep-88 | 2271 | 1534 | 1660 | 1435 | 2902 |
| 10-Sep-88 | 2318 | 1764 | 1787 | 1450 | 1947 |
| 11-Sep-88 | 2289 | 1311 | 1933 | 1383 | 1730 |
| 12-Sep-88 | 2338 | 1664 | 926  | 1430 | 1633 |
| 13-Sep-88 | 2328 | 1558 | 1625 | 1447 | 1653 |
| 14-Sep-88 | 2287 | 1384 | 1783 | 1443 | 1598 |
| 15-Sep-88 | 2461 | 1612 | 1117 | 1229 | 1791 |
| 16-Sep-88 | 2305 | 1772 | 2000 | 1498 | 1849 |
| 17-Sep-88 | 2323 | 1139 | 2079 | 1573 | 1946 |
| 18-Sep-88 | 2378 | 1599 | 1861 | 1500 | 1927 |
| 19-Sep-88 | 2219 | 1675 | 1859 | 1060 | 1890 |
| 20-Sep-88 | 2342 | 1514 | 1905 | 1670 | 1514 |
| 21-Sep-88 | 2313 | 924  | 1849 | 864  | 1673 |
| 22-Sep-88 | 2318 | 1638 | 1136 | 1385 | 1419 |
| 23-Sep-88 | 2544 | 1312 | 1619 | 1317 | 1872 |
| 24-Sep-88 | 2589 | 1548 | 1978 | 1194 | 1751 |
| 25-Sep-88 | 2462 | 1779 | 1811 | 1548 | 1839 |
| 26-Sep-88 | 2534 | 1349 | 1725 | 1498 | 1803 |
| 27-Sep-88 | 2473 | 1412 | 1810 | 1583 | 1326 |
| 28-Sep-88 | 2588 | 1557 | 2191 | 1129 | 1755 |
| 29-Sep-88 | 2340 | 1185 | 2007 | 1454 | 1770 |
| 30-Sep-88 | 2411 | 1625 | 2039 | 1569 | 1786 |
| 01-Oct-88 | 2336 | 1663 | 1990 | 1509 | 1537 |
| 02-Oct-88 | 2484 | 1713 | 1769 | 1535 | 1783 |
| 03-Oct-88 | 2567 | 1914 | 1943 | 1512 | 1715 |
| 04-Oct-88 | 2623 | 1495 | 2052 | 1162 | 1390 |
| 05-Oct-88 | 2802 | 1543 | 1662 | 1295 | 1581 |
| 06-Oct-88 | 2625 | 1290 | 1489 | 1443 | 1494 |
| 07-Oct-88 | 2490 | 1446 | 1658 | 1258 | 1612 |
| 08-Oct-88 | 2404 | 1681 | 1665 | 1429 | 1669 |
| 09-Oct-88 | 2439 | 1613 | 1479 | 1420 | 1611 |
| 10-Oct-88 | 2439 | 1683 | 1666 | 1380 | 2034 |
| 11-Oct-88 | 1575 | 1235 | 1915 | 1055 | 1283 |
| 12-Oct-88 | 862  | 635  | 806  | 849  | 1048 |
| 13-Oct-88 | 702  | 223  | 233  | 290  | 279  |
| 14-Oct-88 | 667  | 709  | 1170 | 668  | 819  |
| 15-Oct-88 | 1603 | 580  | 758  | 1448 | 638  |
| 16-Oct-88 | 2394 | 1112 | 1474 | 1402 | 1765 |
| 17-Oct-88 | 2549 | 1573 | 1951 | 1471 | 1698 |
| 18-Oct-88 | 2217 | 1112 | 1430 | 1412 | 1726 |
| 19-Oct-88 | 2324 | 1241 | 1783 | 897  | 1589 |
| 20-Oct-88 | 2243 | 1400 | 1421 | 1423 | 1604 |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 21-Oct-88 | 2271 | 1706 | 2171 | 1583 | 1657 |
| 22-Oct-88 | 2239 | 1460 | 1848 | 1280 | 1477 |
| 23-Oct-88 | 2431 | 1560 | 1340 | 1317 | 1379 |
| 24-Oct-88 | 2273 | 1203 | 1365 | 1369 | 1493 |
| 25-Oct-88 | 2077 | 1247 | 1718 | 1145 | 1610 |
| 26-Oct-88 | 2892 | 1103 | 1106 | 1071 | 1297 |
| 27-Oct-88 | 2381 | 1584 | 1920 | 1496 | 1565 |
| 28-Oct-88 | 2211 | 1299 | 1873 | 1512 | 1324 |
| 29-Oct-88 | 2076 | 1421 | 1879 | 1565 | 1846 |
| 30-Oct-88 | 2234 | 1491 | 1933 | 1542 | 1839 |
| 31-Oct-88 | 2053 | 1653 | 1674 | 1596 | 1669 |
| 01-Nov-88 | 1961 | 7655 | 1480 | 1580 | 1458 |
| 02-Nov-88 | 2205 | 1314 | 1993 | 1491 | 1240 |
| 03-Nov-88 | 2105 | 901  | 1858 | 1330 | 1701 |
| 04-Nov-88 | 2219 | 1117 | 2323 | 1290 | 1714 |
| 05-Nov-88 | 2249 | 1525 | 1773 | 1540 | 1691 |
| 06-Nov-88 | 1569 | 1608 | 2024 | 1419 | 1921 |
| 07-Nov-88 | 2889 | 1149 | 1962 | 1532 | 1872 |
| 08-Nov-88 | 2231 | 1513 | 1983 | 1449 | 1779 |
| 09-Nov-88 | 2168 | 1210 | 1597 | 1492 | 1746 |
| 10-Nov-88 | 2138 | 1643 | 1964 | 1198 | 1692 |
| 11-Nov-88 | 2177 | 1508 | 1999 | 1380 | 1780 |
| 12-Nov-88 | 1999 | 1492 | 2102 | 1603 | 1618 |
| 13-Nov-88 | 2111 | 1978 | 2032 | 1557 | 1743 |
| 14-Nov-88 | 2051 | 1641 | 1225 | 1645 | 1931 |
| 15-Nov-88 | 2088 | 1506 | 1569 | 2589 | 1408 |
| 16-Nov-88 | 2040 | 1401 | 1834 | 2552 | 1209 |
| 17-Nov-88 | 2040 | 1328 | 1835 | 1266 | 1572 |
| 18-Nov-88 | 2164 | 1573 | 1244 | 1149 | 1623 |
| 19-Nov-88 | 2080 | 1383 | 1763 | 1508 | 1774 |
| 20-Nov-88 | 2169 | 1010 | 1635 | 1436 | 1633 |
| 21-Nov-88 | 2287 | 1015 | 1504 | 1436 | 1806 |
| 22-Nov-88 | 1953 | 1332 | 1004 | 1390 | 1577 |
| 23-Nov-88 | 2151 | 1362 | 1338 | 1416 | 976  |
| 24-Nov-88 | 2097 | 1546 | 1011 | 1461 | 1452 |
| 25-Nov-88 | 2172 | 1541 | 1717 | 1354 | 1567 |
| 26-Nov-88 | 2316 | 1414 | 1304 | 1211 | 1554 |
| 27-Nov-88 | 2140 | 1578 | 1305 | 1252 | 1486 |
| 28-Nov-88 | 2057 | 1384 | 1777 | 1267 | 1399 |
| 29-Nov-88 | 2150 | 1299 | 917  | 1164 | 1238 |
| 30-Nov-88 | 2192 | 1371 | 1586 | 1282 | 1378 |
| 01-Dec-88 | 2024 | 1274 | 1209 | 1234 | 1413 |
| 02-Dec-88 | 2097 | 1530 | 1455 | 1457 | 1503 |
| 03-Dec-88 | 2066 | 1485 | 1127 | 1401 | 1572 |
| 04-Dec-88 | 2009 | 1476 | 1362 | 1434 | 1750 |
| 05-Dec-88 | 2158 | 1521 | 1410 | 1329 | 1706 |
| 06-Dec-88 | 2046 | 1090 | 1662 | 1349 | 1266 |
| 07-Dec-88 | 2109 | 1483 | 1619 | 1917 | 1695 |
| 08-Dec-88 | 2075 | 1413 | 1112 | 1891 | 1594 |

| DATE      | NAV  | OTS  | BLE  | RBN  | ELD  |
|-----------|------|------|------|------|------|
| 09-Dec-88 | 1970 | 1282 | 1402 | 1290 | 1461 |
| 10-Dec-88 | 2073 | 1000 | 1340 | 1585 | 1352 |
| 11-Dec-88 | 1895 |      | 1684 | 1409 | 1622 |
| 12-Dec-88 | 1995 | 730  | 1734 | 1003 | 1485 |
| 13-Dec-88 | 2127 | 1498 | 1842 | 1447 | 1045 |
| 14-Dec-88 | 2062 | 1387 | 1426 | 956  | 1443 |
| 15-Dec-88 | 2158 | 1427 | 1006 | 1047 | 1408 |
| 16-Dec-88 | 2217 | 979  | 1843 | 1260 | 1489 |
| 17-Dec-88 | 2221 | 1449 | 1761 | 2157 | 1224 |
| 18-Dec-88 | 2120 | 1533 | 1701 | 1902 | 1505 |
| 19-Dec-88 | 2061 | 1577 | 1223 | 929  | 1385 |
| 20-Dec-88 | 2087 | 1156 | 1777 | 1295 | 1500 |
| 21-Dec-88 | 2098 | 1655 | 1651 | 943  | 1482 |
| 22-Dec-88 | 2096 | 1157 | 1667 | 1390 | 1441 |
| 23-Dec-88 | 2156 | 1340 | 1879 | 2451 | 1514 |
| 24-Dec-88 | 2197 | 1665 | 1814 | 2238 | 1574 |
| 25-Dec-88 | 2151 | 1794 | 2028 | 2402 | 1641 |
| 26-Dec-88 | 2248 | 1556 | 1915 | 1631 | 1507 |
| 27-Dec-88 | 2012 | 1333 | 1001 | 1202 | 1396 |
| 28-Dec-88 | 2107 | 1733 | 1687 | 1058 | 1450 |
| 29-Dec-88 | 2387 | 1494 | 967  | 1407 | 1464 |
| 30-Dec-88 | 2041 | 1340 | 1916 | 1439 | 1429 |
| 31-Dec-88 | 2231 | 1489 | 1833 | 1252 | 1396 |

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## VITA

Captain Kenneth R. Norton [REDACTED]

[REDACTED] He graduated from Braintree High School in June 1978 and entered the Massachusetts Maritime Academy for one year. In June of 1979 he entered the United States Air Force Academy. While at the Air Force Academy he boxed and was the wing runnerup in the 185 weight class his senior year. He graduated from the Air Force Academy with a Bachelor of Science degree in Mathematics in June 1983.

Captain Norton was assigned with the North American Aerospace Defense Command, United States Space Command, and Air Force Space Command from July 1983 to April 1989. During this period, he worked as an Orbital Analyst, Orbital Analyst Instructor, and Space Surveillance Center Commander Instructor in the Space Surveillance Center. He was responsible for developing the training program for two combat positions while remaining crew qualified in both positions. He has earned Space Command's skilled and expert awards. In May 1989, Captain Norton entered the School of Engineering, Air Force Institute of Technology at Wright-Patterson Air Force Base, Ohio.

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| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                             |                                                            | Form Approved<br>JUNE 1975 EDITION<br>GSA GEN. REG. NO. 27             |  |
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| 11. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                             |                                                            |                                                                        |  |
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| 13. ABSTRACT (Maximum 200 words)<br><p>The relationship between the size of the United States Air Force Space Command's lost satellite lists and thirteen other variables is investigated. The thirteen variables contain the Space Surveillance Center crew's effort to work the lost list, solar activity, geomagnetic field strength, and the number of observations received each day from seven space track sensors. To identify the relationship of cause and effect between the lost lists and the thirteen variables, simple and multiple linear regressions are used on a data set that begins on 1 January 1988 and ends on 31 December 1988. Multiple linear regression and basic time-series smoothing techniques are used to forecast the number of lost satellites.</p> <p>The results of this study show that solar activity causes near earth satellites to "go lost". This study also shows that not all sensors respond to increases in the size of lost lists in the same manner. Finally, the best forecast for the size of the lost satellite lists is provided by a multiple linear regression.</p> |                                                             |                                                            |                                                                        |  |
| 14. SUBJECT TERMS<br>Spacecraft Debris, Debris, Orbits, Correlation,<br>Artificial Satellites, Lost Satellites, Space<br>Surveillance Systems                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                             |                                                            | 15. NUMBER OF PAGES<br>108                                             |  |
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