NOAA Technical Memorandum NOS NGS-47

ADJUST: THE HORIZONTAL OBSERVATION ADJUSTMENT PROGRAM

Dennis G. Milbert
William G. Kass

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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service / Office of Charting and Geodetic Services

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CONTENTS

Abstract..... 1
1. Introduction..... 1
2. User instructions..... 2
3. Mathematical models..... 28
4. Program implementation..... 46
Acknowledgments..... 52
References..... 52

Tables

2.1 Blue Book records..... 3
2.2 ADJUST adjustment file formats..... 12
2.3 Anticipated error messages..... 23
2.4 Diagnosis of data messages..... 24
2.5 Programmer messages..... 26
3.1 Symbols and definitions..... 35
3.2 General equations..... 36
3.3 Mathematical models (mark-to-mark)..... 36
3.4 Observation equations (mark-to-mark)..... 37
3.5 Coefficients of observation equations..... 38
3.6 Modified observation models..... 41
3.7 Auxiliary parameter coefficients..... 42
3.8 General error analysis equations..... 45
4.1 Arrays stored in A() array..... 51

Examples

2.1 IBM JCL..... 4
2.2 HP 9000 UNIX..... 5
2.3 ADJUST output sections..... 9

Figures

3.1 Local geodetic horizon system..... 29
3.2 Local astronomic horizon system..... 29
3.3 Top view..... 35
3.4 Side view..... 35
3.5 Perspective view..... 35
4.1 Main memory map..... 47
4.2 Data storage block map..... 48
4.3 Googe number map..... 48
4.4 Position shift memory map..... 49
4.5 GPS work area map..... 49

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ABSTRACT: ADJUST is a highly transportable computer code written in ANSI standard FORTRAN 77 for adjusting numerous kinds of geodetic observations in one, two, or three dimensions. This document describes the input, output, and processing performed by ADJUST.

1. INTRODUCTION

The ADJUST program is a major tool for the least squares adjustment of horizontal, vertical angle, and Global Positioning System (GPS) survey networks submitted to the National Geodetic Survey (NGS). The authors have taken great care in using a structured, top down approach in writing the code using ANSI standard FORTRAN 77 (ANSI X3.9-1978). The benefits from this approach are reliability, transportability, and maintainability.

Previously the Horizontal Network Branch (HNB) employed several adjustment programs. These included the one-dimensional vertical adjustment program VERT02, the two-dimensional horizontal adjustment program TRAV10 (Schwarz 1978), and the three-dimensional adjustment program HAVAGO (Vincenty 1979). One advantage of ADJUST compared to the above programs is its multidimensional capability. Users need only to become familiar with ADJUST instead of three radically different programs.

ADJUST uses up to three external input files. Two of these, BBOOK and GFILE, adhere to formats defined in the Federal Geodetic Control Committee (FGCC) publication Input Formats and Specifications of the National Geodetic Survey Data Base, volume 1, Horizontal Control Data (Pfeifer 1980), which is informally referred to as the "Blue Book." BBOOK includes horizontal directions and angles, zenith distances, distances, azimuths, Global Positioning System (GPS) records and survey point data, i.e., geodetic positions, geoid heights, and deflections. Another input file, named GFILE, contains GPS vectors and their standard deviations and correlations. This file need not be present if no GPS data are in the adjustment. The third input file, AFILE, is the adjustment file. The AFILE will give the user a large variety of options and will be discussed in detail in the following section.

Prior to using the ADJUST program, NGS will always run two separate programs, CHKOBS and MODBB. Briefly, CHKOBS verifies the format of the Blue Book horizontal observation data according to the FGCC format specifications. MODBB will modify certain Blue Book horizontal observation data record fields into a mark-to-mark form while still maintaining valid FGCC format specifications. MODBB also converts Blue Book *81* Control Point Records, State Plane

Coordinates (SPC) and Universal Transverse Mercator (UTM), into Blue Book *80* Control Point Records (geodetic coordinates).

The remainder of this publication is divided into three sections. Section 2 covers the user instructions. This includes preliminary instructions, file name convention, sample executions, discussions of results, construction of the Adjustment File (AFILE), input/output file formats, and error messages. The aim is to provide a basic step-by-step explanation of ADJUST.

Section 3 details mathematical models and covers the least squares adjustment model, observation models, and variance models. Unlike the previous section, this material provides a reference for the geodesist or geodetic engineer. Section 4 discusses program implementation. This final section also features extensions and special compiler options geared for a programmer or a software engineer. Sufficient detail is provided to enable the user to modify ADJUST for individual needs.

2. USER INSTRUCTIONS

This section contains instructions for running ADJUST. The input is briefly discussed. We then show two examples of execution. A description of some typical output of ADJUST is given as well as detailed instructions for the construction of the option file AFILE. The end of the section covers error messages.

Input

Program ADJUST uses three external input files: (1) AFILE, (2) BBOOK, and (3) GFILE. The AFILE is the Adjustment File that combines a full range of parameter selections and error analysis features; the BBOOK is the horizontal, vertical angle, and GPS survey data; and the GFILE is the GPS data transfer format. The format specifications of the Adjustment File (AFILE) will be determined in the latter part of this chapter. A discussion of the BBOOK and GFILE input files follows.

The format specifications of the BBOOK records and the GPS G-Format (GFILE) records are both defined in Input Formats and Specifications of the National Geodetic Survey Data Base, volume 1, Horizontal Control Data. The user will always have an AFILE because it is used to indicate which points should be constrained in the adjustment. The BBOOK is mandatory. When no GPS data are present in the adjustment, the GFILE need not be present.

BBOOK is the file containing horizontal directions and angles, zenith distances, distances, azimuths, GPS records, and survey point data (i.e., geodetic positions, geoid heights and deflections). BBOOK is the only input file that must go through checking programs: (1) CHKOBS and (2) MODBB. Table 2.1 contains a list of possible BBOOK records.

CHKOBS verifies the input format according to the FGCC format specifications. MODBB will modify certain FGCC horizontal and vertical observational data record fields into a mark-to-mark form while still maintaining valid FGCC format specifications. MODBB will compute the one-sigma estimate (standard error) for each observation listed in the prescribed format. MODBB will also convert *81* Control Point Records (SPC/UTM) into *80* Control Point Records (geodetic

coordinates). Failure to run these two programs could lead to excessive error messages or invalid results.

Table 2.1.--Blue Book Records

aa	Data Set Identification Record
10	Project Title Record
11	Project Title Continuation Record
12	Project Information Record
13	Geodetic Datum and Ellipsoid Record
20	Horizontal Direction Set Record
21	Horizontal Direction Comment Record
22	Horizontal Direction Record
25	GPS Occupation Header Record
26	GPS Occupation Comment Record
27	GPS Occupation Measurement Record
28	GPS Clock Synchronization Record
29	GPS Clock Synchronization Comment Record
30	Horizontal Angle Set Record
31	Horizontal Angle Comment Record
32	Horizontal Angle Record
40	Vertical Angle Set Record
41	VerticaL Angle Comment Record
42	Vertical Angle Record
50	Taped Distance Record
51	Unreduced Distance Record
52	Reduced Distance Record
53	Unreduced Long Line Record
54	Reduced Long Line Record
55	Distance Comment Record
60	Laplace Azimuth Record
61	Geodetic Azimuth Record
70	Instrument Record
80	Control Point Record
81	Control Point Record (UTM/SPC)
82	Reference or Azimuth Mark Record
83	Bench Mark Record
84	Geoid Height Record
85	Deflection Record
90	Fixed Control Record
aa	Data Set Termination Record

The GFILE contains GPS data in G-Format. The G-Format has four different record types: (1) the Project Record, (2) the Group Header Record, (3) the Member Record, and (4) the Correlation Record. The GFILE records are derived from the FGCC input formats for GPS data records along with the carrier phase measurements (recorded on magnetic tape). Each job contains one Project Record which consists of one or more Group Header Records. A Group Header Record is required for each group of simultaneous phase measurements at the survey points. With each Group Header Record is associated one or more Member and Correlation Records. The Member Record reflects the computed vector information between the

survey points, and the Correlation Record reflects the correlation of various vector components.

Departures from the Blue Book Format

The Blue Book format was designed as a specification for data submission. However, departures from the format are necessary for data processing. Since a specification with numerous modifications is no specification at all, the departures are kept very small.

Columns 1 through 6 are no longer assumed to contain a sequential number.

An observation may be flagged for rejection by placing "R" in column 6 of an observation record (*20*, *22*, *30*, *32*, *40*, *42*, *52*, *54*, *60*).

The external consistency field (77-80) is used to hold the aggregate observation standard deviation. Units are seconds of arc for angular measurements, millimeters for *52* records, and meters for *54* records.

Warning: To encode a 5 cm standard deviation on a *52* record, for example, use "$_{\Delta}$500" or "$_{\Delta}$50." in columns 77-80. DO NOT use ".050".

To encode a 5 cm standard deviation on a *54* record, use either "$_{\Delta\Delta}$5" or ".05".

Sample Execution

The following examples will demonstrate sample executions of program ADJUST. Example 2.1 uses IBM Job Control Language (JCL) while example 2.2 utilizes the HP-9000 using UNIX. Both of these examples include the optional input files, GFILE, and AFILE.

Example 2.1.--IBM JCL

```
//NGSXXX   JOB (BIN#,A035,,,,,,,,EXECUTE),'NAME'
//*
//*** TRANSLATE A WYLBUR FILE TO CARD FORMAT
//*
//DECODE EXEC EDUTIL,COMMAND='COPY DDNAME=IN TO DDNAME=OUT'
//IN DD DSN=DS.NGSXXX.BBOOK,UNIT=3330-1,
//      VOL=SER=DISKNAME,DISP=SHR
//OUT DD DSN=&&TEMP1,DISP=(NEW,PASS),UNIT=SYSDA,
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),SPACE=(TRK,(10,5),RLSE)
//*
//*** TRANSLATE A WILBUR FILE TO CARD FORMAT
//*
//DECODE2 EXEC EDUTIL,COMMAND='COPY DDNAME=IN TO DDNAME=OUT'
//IN DD DSN=DS.NGSXXX.AFILE,UNIT=3330-1,
//       VOL=SER=DISKNAME,DISP=SHR
//OUT DD DSN=&&TEMP2,DISP=(NEW,PASS),UNIT=SYSDA
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),SPACE=(TRK,(10,5),RLSE)
//*
//*** TRANSLATE A WYLBUR FILE TO CARD FORMAT
```

```
//*
//DECODE3 EXEC EDUTIL,COMMAND='COPY DDNAME=IN TO DDNAME=OUT'
//IN DD DSN=DS.NGSXXX.GFILE,UNIT=3330-1,
//      VOL=SER=DISKNAME,DISP=SHR
//OUT DD DSN=&&TEMP3,DISP=(NEW,PASS),UNIT=SYSDA
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),SPACE=(TRK,(10,5),RLSE)
//*
//***    LOAD LIBRARY (FORTRAN 77)
//*
//GPSRUN EXEC PGM=ADJUST,REGION=4000K
//STEPLIB DD DSN=DS.NGSXXX.LIBS,UNIT=3330-1, VOL=SER=DISKNAME,DISP=SHR
//        DD DSN=SYS2.VSFORT.R3M0.VRENTLIB,DISP=SHR
//BBOOK DD DSN=&&TEMP1,DISP=(OLD,DELETE)
//AFILE DD DSN=&&TEMP2,DISP=(OLD DELETE)
//GFILE DD DSN=&&TEMP3,DISP=(OLD,DELETE)
//FT06F001 DD SYSOUT=A
//FT08F001 DD UNIT=SYSDA,SPACE=(TRK,(10,5)),
//       DCB=(RECFM=VBS,LRECL=140,BLKSIZE=400)
//FT09F001 DD UNIT=SYSDA,SPACE=(TRK,(10,5)),
//       DCB=(RECFM=VBS,LRECL=140,BLKSIZE=400
//
```

Example 2.2.--HP 9000 UNIX

```
(file names:)
      adjust.f
      AFILE
      BBOOK
      GFILE
(command to compile and link source code:)
(Note:  The executable will be defaulted to the name a.out)
     fc  -s   adjust.f
(command to execute program:)
     a.out > list
(output will be found in the file "list")
```

Typical Output

The following discussion will explain what the user sees when requesting the most elaborate output from ADJUST (mode three). You may wish to refer to outline 2.3 as you read this material. On the first page of the ADJUST listing, the user will find the AFILE contents. This simply echoes the AFILE to assist in error checking.

Next, ADJUST lists the options the user has selected through the AFILE. Here, the user can verify options such as the selected ellipsoid, the default mean sea level and geoid height, whether or not to adjust orthometric elevations, scale sigmas by the a posteriori sigma or to update the geodetic positions (*80* records in the Blue Book). In addition, the user can confirm the dimensionality of the adjustment, set a maximum number of iterations, abort if a misclosure exceeds a certain sigma and converge if the root mean square (rms) sum of the shifts in meters falls below an arbitrary number. Other options control the output of ADJUST. It is possible to bypass the display of all or parts of BBOOK or GFILE, and bypass types of residuals and post-processing statistics.

The next section displays the constraints requested in the AFILE. To the left of each constraint is displayed the observation number (OBS#). If any constraint has a large misclosure (defined as the observed value minus the computed value divided by the standard deviation), the misclosure and the observation number will be flagged as excessive prior to the listing of the constraint itself.

The next two sections display the Blue Book (BBOOK) and the GPS observations (GFILE), respectively. The AFILE gives the user the choice of viewing the entire input file, only the observations, or only the large misclosures of either file. ADJUST displays the observation number on the left and any large misclosure on the right of each valid observation record. The GPS observations display the observation number on the left. Large misclosures are flagged after the observation records. An "R" in column six on a Blue Book observation signifies that observation is rejected. In this case, no observation number will appear on the left. An "R" in column 58 on a GFILE C-record (member record) rejects that GPS vector.

The "Observational Summary" appears after the BBOOK and GFILE sections. From left to right are displayed the Station Serial Number (SSN), the station name and the quantities of the "from" and "to" directions (DIR), angles (ANG), azimuths (AZI), distances (DIS), zenith distances (ZD) and GPS observations. Every station in the *80* records of the BBOOK will appear in the Observational Summary. Code letters will appear after the SSN's in this section. A "C" denotes that the station is constrained in latitude, longitude and height, an "N" means the station is a no-check station, a "U" signifies that the station is undetermined, and a blank indicates that the station has enough observational strength. A "U" will ultimately result in a singular solution. If U's are present then ADJUST is immediately terminated.

The next section is titled "Commencing Adjustment." The first line after the title reveals the iteration number, the root mean square (rms) of the coordinate corrections, the sum of the weighted squares of residuals (VTPV), the degrees of freedom (DF) and the variance. The adjustment starts at the zero iteration and cycles to convergence or to the maximum number of iterations. The number of iterations may be changed using the AFILE. The rms correction is the sum of all the corrections to the latitudes, the longitudes, and the orthometric heights divided by the number of stations times the number of adjusted dimensions (dimensionality). The rms correction is used to determine convergence. The degrees of freedom are computed by adding the number of observations plus the number of constraints minus the number of unknowns. Finally, the a posteriori variance of unit weight is computed by dividing the VTPV by the degrees of freedom. The expected value of the variance of unit weight is one. Outliers, systematic errors, incorrect weights, and random errors will cause deviations in the expected value.

After the above statistics are displayed, the next line shows the maximum shift. It displays the station name and the latitude, longitude, or vertical shift in meters. Several large misclosures with their observation number may also be listed. The above statistics will appear during each iteration cycle until the adjustment converges or encounters problems. A problem with convergence could be a diverging solution or a slowing converging solution. Misidentification or extremely weak geometry can cause convergence problems.

If variance factors are also being computed, they are displayed in the iteration cycles. The sequence number, the variance factor, the degree of freedom and the variance factor ratio (computed divided by the initial) are displayed from left to right. The iteration number, the RMS correction, the VTPV, the degree of freedom and the variance are once again displayed. If a variance factor is constrained, then the effect is equivalent to scaling the weight of those observations.

The following section, "Job Statistics," inventories the Blue Book and the number of constraints, accuracies, and rejected observations. The Blue Book statistics are further broken down into the number of *80* Control Point Records, *84* Geoid Height Records, *85* Deflection Records and the number of directions, angles, GPS vectors, zenith distances, and azimuths.

The heading of the next section varies depending on the mode of computation. The mode three heading is "Normalized Residuals." It displays the observational sequence number, the observational type, the computed and the observed observation, the residual (adjusted minus observed value) in seconds and/or meters, the standard deviation of the residual (SDV), the normalized residual (V/SDV), the marginal detectable error (MDE) using three sigma, the redundancy number (RN) and finally the station name or names. The various types of observations include the latitude (LA), longitude (LO), and ellipsoid height (EH) constraints, auxiliary parameter (AP) constraints, azimuths (AZ), zenith distances (ZD), horizontal angles (HA), horizontal directions (HD), distances (DIST) and the three GPS vectors (DX, DY, DZ). Constrained azimuths (CA), distances (CD), zenith distances (CZ), geoid height differences (DN), orthometric height differences (DO), and ellipsoidal height differences (DE) are additional observation types.

The MDE is in units of meters or seconds and indicates the internal reliability of a network. The user can examine the MDE for each observation and ascertain how large a misclosure can become before the standardized residual reaches a critical value of three. The redundancy numbers are unitless and indicate the reliability of the adjustment of individual observations (El-Hakim 1981). A redundancy number of one is totally redundant, and will not influence the coordinate. A zero redundancy number will not detect any blunders (no-check). Using the above statistics (error analysis), the user can make a sound decision whether or not to reject an observation. Note that the redundancy numbers are summed for GPS observations. The numbers will range from 0 through 3*n, where n is the number of vectors in a group.

After the residuals themselves, "Residual Statistics" shows additional residual information. This section gives 20 observation numbers of the largest standardized residuals (V/SDV). The total number of observations, the total number of no-checks (residuals equaling zero), the maximum, minimum, and mean residual and normalized residuals are displayed. This is followed by a table which varies depending on the mode of computation. Using the third mode, the rows are labeled delta X, Y, and Z, direction, angle, zenith distance, distance, azimuth, other, and total. The row labeled "other" includes all of the constraints. The columns accumulate the number of observations (N), the VTPV, the RMS VTPV, the redundancy numbers (RN), the VTPV divided by the redundancy number, and the mean absolute residuals in meters or seconds. These numbers are summed and then totaled in the last row. The last part of this section simply

yields the degrees of freedom, variance sum, the standard deviation of unit weight, and the variance of unit weight.

The next section of the output, "Adjusted Auxiliary Parameters," only exists if auxiliary parameters were requested in the AFILE. The output displays the sequence number, the values of the auxiliary parameter, the scaled (or unscaled) sigma, the Googe number (Schwarz 1978: 29-32), and the value of the auxiliary parameter divided by the standard deviation. Googe numbers are the result of normalization of the diagonal elements in the normal equations. They range from zero to one and they aid in the detection of singularities. A singularity is caused by a weakness in the strength of the network and results in a Googe number being very close to zero.

The section "Adjusted Auxiliary GPS Rotation Parameters" will only appear if GPS rotation parameters were requested in the AFILE. The output shows value of the rotation, scaled (or unscaled) sigma, the ratio of the rotation to its standard deviation, and the Googe number.

"Normalized Residuals Grouped Around Intersection Stations" then follow. ADJUST loops through the observations, station by station, to display the observational sequence number, the observational type, the computed and observed observation, the misclosure, the normalized residual, the redundancy number, and the "From" station and "To" station which would be the intersection station. Again, the mode of computation could alter the title and output of this section.

The next section is titled "Adjusted Positions." Reading from left to right are the sequence number, the station serial number found on the *80* record in the Blue Book, the adjusted latitude, longitude, mean sea level (MSL), the geoid height, and the adjusted ellipsoid height. Under each adjusted position, the shifts in meters, and the Googe numbers for the latitude, longitude, and ellipsoid height for each station are also displayed. The azimuth of the positional shift, the horizontal shift, and the total shift of each station appears on the far right side of the page.

The final section exists only if QQ records appear within AFILE. QQ records compute "Length Relative Accuracies." For every QQ-record in the AFILE, four lines of output are displayed. The first line gives the "From" and "To" station names and station serial numbers. The second line outputs the distance between the two stations, the standard deviation of the distance, and the relative accuracy. Also shown is the horizontal shift and the relative accuracy of the horizontal shift. The first accuracy is computed by dividing the distance between the two stations by the standard deviation of the computed observation, while the second accuracy is obtained by dividing the distance by the horizontal shift. Accuracies play an important role in determining the order and class of the survey (FGCC 1984). The other two lines of output display the azimuth and vertical angle between the stations along with the standard deviation of the computed value.

After the end of the accuracy processing the user will see, "End of ADJUST Process, Have a Nice Day." We hope that with the preceding discussion and with the following sections, this will be an appropriate closing remark.

Outline 2.3.--ADJUST output sections (mode three)

1. AFILE CONTENTS

2. AFILE OPTIONS

3. CONSTRAINTS (optional, default will display all constraints)
   a) Observation Sequence Number (OSN)
   b) Constrained Records
   c) Large Misclosures

4. BLUE BOOK (optional, default will print)
   a) OSN
   b) Blue Book Records
   c) Large Misclosures

5. GPS OBSERVATIONS (optional, default will print)
   a) OSN
   b) GPS Data Record
   c) Large Misclosures

6. OBSERVATIONAL SUMMARY (optional, default will print)
   a) Station Serial Number (SSN)
   b) Station Information
      (1) "C" - constraint
      (2) "N" - no-check
      (3) "U" - undetermined
   c) Station Name
   d) Direction
      (1) From
      (2) To
   e) Horizontal Angle
      (1) From
      (2) To
   f) Azimuth
      (1) From
      (2) To
   g) Distances
      (1) From
      (2) To
   h) Zenith Distances
      (1) From
      (2) To
   i) GPS
      (1) From
      (2) To

7. COMMENCING ADJUSTMENT
   a) Iteration Number
   b) rms Correction
   c) VTPV (sum of weighted squares of residuals)
   d) Degrees of Freedom (DF)
   e) Variance of Unit Weight
   f) Maximum Station Shift
   g) Large Misclosures

h) Variance Factors (V.F.)
   (1) Number
   (2) Value
   (3) DF
   (4) V.F. Ratio
i) Googe Numbers of Singular (or nearly singular) Unknowns
   (1) SSN
   (2) Station Name
   (3) Unknown
   (4) Googe Number

8. JOB STATISTICS
   a) Blue Book Statistics
      (1) No. *80* Control Cards
      (2) No. *84* Geoid Height Records
      (3) No. *85* Deflection Records
      (4) No. Directions
      (5) No. Angles
      (6) No. GPS Vectors
      (7) No. Zenith Distances
      (8) No. Distances
      (9) No. Azimuths
   b) No. Constraints
   c) No. Accuracies
   d) No. Rejected Observations

9. NORMALIZED RESIDUALS
   a) DIRECTIONS (optional, default will print)
      (1) OSN
      (2) Observational Type
      (3) Computed Observation (C)
      (4) Observed Observation (O)
      (5) Residual (V=C-O)
      (6) Standard Deviation of the Residual (SDV)
      (7) Normalized Residual (V/SDV)
      (8) Marginal Detectable Error (MDE) using 3-sigma
      (9) Redundancy Number (RN)
      (10) Station Names
   b) ANGLES (optional, default will print)
      (1-10) Same as above
   c) ZENITH DISTANCES (optional, default will print)
      (1-10) Same as above
   d) DISTANCES (optional, default will print)
      (1-10) Same as Above
   e) ASTRONOMIC AZIMUTHS (optional, default will print)
      (1-10) Same as above
   f) GPS (optional, default will print)
      (1-10) Same as above
   g) CONSTRAINTS (optional, default will print)
      (1-10) Same as above

10. RESIDUAL STATISTICS
   a) OSN of the 20 greatest standardized residuals (V/SDV)

b) Some statistics based on normalized residuals (except no-check)
   (1) Total number of observations
   (2) Number of no-checks
   (3) Minimum V and V/SDV
   (4) Maximum V and V/SDV
   (5) Mean V and V/SDV
c) Some statistics based on residuals
   (1) Number of observations (N)
   (2) VTPV
   (3) RMS VTPV
   (4) Redundancy Number (RN)
   (5) VTPV/RN
   (6) Mean absolute residual
d) DF, VTPV, STD. DEV. and Variance of Unit Weight

11. ADJUSTED AUXILIARY PARAMETERS (exist only if auxiliary parameters exist)
   a) Auxiliary Parameter Number
   b) Auxiliary Parameter Value
   c) Scaled or Unscaled Sigma
   d) Googe Number
   e) Value/Sigma

12. ADJUSTED AUXILIARY GPS ROTATION PARAMETERS (only if GPS bias parameters exist)
   a) Rotation Parameter Number
   b) Rotation Parameter Values
   c) Scaled or Unscaled Sigmas
   d) Value/Sigma
   e) Googe Numbers

13. NORMALIZED RESIDUALS GROUPED AROUND INTERSECTION STATIONS (optional)
   a) OSN
   b) Observational Type
   c) Computed Observation
   d) Observed Observation
   e) Residual (V=C-O)
   f) V/(SDV)
   g) Redundancy Number
   h) Station Names

14. LIST OF ADJUSTED POSITIONS (optional, default will print)
   a) SSN
   b) Station Name
   c) Latitude (shifts, sigmas, Googe No.)
   d) Longitude (shifts, sigmas, Googe No.)
   e) Mean Sea Level (MSL)
   f) Geoid Height (G.HT.)
   g) Ellipsoid Height (E. HT. - shifts, sigmas, Googe No.)
   h) Azimuth (shift)
   i) Horizontal (shift)
   j) Total (shift)

15. LENGTH RELATIVE ACCURACIES (using a-priori weights)

a) Station Names and SSN
b) Distance (sigma, accuracy, horizontal shift, accuracy)
c) Azimuth (sigma)
d) Vertical Angle (sigma)
e) Vertical Angle (sigma)

Construction of the Adjustment File

The Adjustment File (AFILE) provides control of the many options available in program ADJUST. Every option that can be selected has a default value or default state. These defaults have been selected to provide the usual result a user would desire. Most fields on a record have a default value, so every field on a record does not have to be encoded. In most instances, the AFILE will be short, and the records that are present will be almost completely empty.

Eighteen different record types are available to construct an AFILE; each record has a two character code, which appears in the first two columns. Table 2.2 displays the format for each record. The contents of each field are typically right justified integers or alphanumeric codes.

Table 2.2.--ADJUST adjustment file formats

Type	Description
AA	Ellipsoid Parameter Record
BB	Bypass Record
CC	Constrained Coordinate Record
CA	Constrained Azimuth Record
CD	Constrained Distance Record
CH	Constrained Height Difference Record
CZ	Constrained Zenith Distance Record
DD	Dimensionality Record
EE	Default Mean Sea Level Elevation Record
GG	Default Geoid Height Record
HD	Default Height Adjustment Record
HC	Control Point Height Adjustment Record
II	Iteration Record
MM	Adjustment Mode Record
PP	Print Output Record
QQ	Accuracy Computation Record
RR	GPS Rotation Parameter Record
SS	Auxiliary Parameter Indicator & Constraint Record
VV	Variance Factor Indicator & Constraint Record

Ellipsoid Parameter Record

01-02	AA
03-12	Semi-Major Axis, optional, default 6378137.000 (real, 3 decimals)
13-30	Square First Eccentricity, optional, default 0.006694380022903415 67 (real, 18 implied decimals)
31-80	Reserved

Bypass Record

01-02	BB		
03-03	Do not bypass directions	(*20*, *22*)	(nonblank to defeat option)
04-04	Do not bypass hor. angles	(*30*, *32*)	(" " " ")
05-05	Do not bypass zen. dist.	(*40*, *42*)	(" " " ")
06-06	Do not bypass distances	(*52*, *54*)	(" " " ")
07-07	Do not bypass azimuths	(*60*)	(" " " ")
08-08	Do not bypass GPS	(G-Format)	(" " " ")
09-80	Reserved		

NOTE: BB records MUST precede all DD, SS, and VV records

Constrained Coordinate Record

01-02	CC	
03-10	Reserved	
11-13	Station Serial Number	(integer)
14-14	Reserved	
15-20	Latitude Standard Deviation, units of mm., default 0.1 mm.	(integer)
21-26	Longitude Standard Deviation, units of mm., default 0.1 mm.	(integer)
27-32	Height Standard Deviation, units of mm., default 0.1 mm.	(integer)
33-44	Reserved	
45-46	Degrees Latitude	(integer)
47-48	Minutes Latitude	(integer)
49-55	Seconds Latitude, units of 0.00001 arc seconds	(integer)
56-56	Latitude Code N -- positive North (default) S -- positive South	
57-59	Degrees Longitude	(integer)
60-61	Minutes Longitude	(integer)
62-68	Seconds Longitude, units of 0.00001 arc seconds	(integer)
69-69	Longitude Code E -- positive East W -- positive West (default)	
70-76	Height, units of millimeters	(integer)
77-80	Reserved	

Constrained Astronomic Azimuth Record (bypass if 1-D adjustment)

01-02	CA	
03-05	Standpoint Station Serial Number	(integer)
06-08	Forepoint Station Serial Number	(integer)
09-11	Reserved	
12-14	Degrees Azimuth	(integer)
15-16	Minutes Azimuth	(integer)
17-20	Seconds Azimuth, units of 0.01 arc second	(integer)
21-25	Azimuth Standard Deviation, units of 0.01 arc second , default of 0.01 arc second	(integer)
26-80	Reserved	

Constrained Distance Record

01-02	CD	
03-05	Standpoint Station Serial Number	(integer)
06-08	Forepoint Station Serial Number	(integer)
09-20	Mark-to-Mark Distance, units of 0.1 mm	(integer)
21-25	Distance Standard Deviation, units of 0.1 mm, default of 0.1 mm	(integer)
26-80	Reserved	

Constrained Height Difference Record (bypass if 2-D adjustment)

01-02	CH	
03-05	Standpoint Station Serial Number	(integer)
06-08	Forepoint Station Serial Number	(integer)
09-20	Height Difference, units of 0.1 mm.	(integer)
21-25	Height Difference Standard Deviation, units of 0.1 mm, default of 0.1 mm	(integer)
26-80	Reserved	

NOTE: If both endpoints adjust orthometric heights, then height difference is considered to be orthometric,
if both endpoints adjust geoid heights, then height difference is considered to be undulation difference,
if one endpoint adjusts orthometric height, and the other adjusts geoid height, height difference is considered to be the ellipsoidal difference.

Constrained Zenith Distance Record (bypass if 2-D adjustment)

01-02	CZ	
03-05	Standpoint Station Serial Number	
06-08	Forepoint Station Serial Number	(integer)
09-11	Reserved	
12-14	Degrees Zenith Distance	(integer)
15-16	Minutes Zenith Distance	(integer)
17-20	Seconds Zenith Distance, units of 0.1 arc second	(integer)
21-25	Zenith Distance Standard Deviation, units of 0.1 arc second, default of 0.01 arc second	(integer)
26-80	Reserved	

Dimensionality Record

01-02	DD	
03-03	Dimensionality	1 -- Height Adjustment
		2 -- Horizontal Adjustment
		3 -- 3-D Adjustment (default)
04-80	Reserved	

Note: DD records must precede all SS and VV records.

Default Mean Sea Level Elevation Record

01-02	EE	
03-09	Default Orthometric Elevation, units of mm, default 0	(integer)
10-80	Reserved	

Default Geoid Height Record

01-02	GG	
03-09	Default Geoid Height, units of mm, default 0	(integer)
10-80	Reserved	

Default Height Adjustment Record

01-02	HD	
03-03	Height Indicator	E -- Adjust Orthometric Elevation (default)
		G -- Adjust Geoid Height
04-80	Reserved	

Control Point Height Adjustment Record

```
01-02  HC
03-03  Height Indicator  E -- Adjust Orthometric Elevations (default)
                         G -- Adjust Geoid Heights
04-06  Station Serial Number
07-80  Reserved
```

Iteration Record

```
01-02  II
03-04  Maximum number of iterations, default 5                      (integer)
05-08  Maximum allowable misclosure, units of sigma, default 300    (integer)
09-11  Minimum printed misclosure, units of sigma, default 30       (integer)
12-17  Coordinate convergence tolerance, units of mm, default 3     (integer)
18-18  Display statistics when solution slowly converges
                         Y -- Display statistics
                         N -- Do not display statistics (default)
19-80  Reserved
```

Adjustment Mode Record

```
01-02  MM
03-03  Mode indicator  0 -- Simulation, bypass cc04-12 of this record
                       1 -- Compute quasi-normal residuals          (default)
                       2 -- Compute q.n. residuals and inverse
                       3 -- Compute normal residuals and inverse
04-04  Post-adjustment indicator  N -- Do NOT scale sigmas by a posteriori
                                       variance factors             (default)
                                  Y -- Scale weights
05-05  Update *80* Control Point Records with adjusted positions
                                  N -- Do NOT update *80* records (default)
                                  Y -- Update *80* records
06-12  New Blue Book filename (alphanumeric; default for the new Blue Book
                                       filename -- 'NEWBB')
```

Print Output Record

```
01-02  PP
03-03  Echo Blue Book File.        0 -- Echo all (default)
                                   1 -- Echo observations only
                                   2 -- Echo large misclosures only
04-04  Echo G-Format File          0 -- Echo all (default)
                                   1 -- Echo observations only
                                   2 -- Echo large misclosures only
05-05  Display Constraints                      (nonblank to defeat option)
06-08  Criteria for Residual Output(XX.x)
       0.0  Display All Residuals(default)
       1.0  Display Only Normalized Residuals Greater or Equal to 1.0
       99.9 Display No Residuals (100,000,000 sigma)
09-09  Display Direction Residuals              (nonblank to defeat option)
10-10  Display Angle Residuals                      "     "     "     "
11-11  Display Zenith Distance Residuals            "     "     "     "
12-12  Display Distance Residuals                   "     "     "     "
13-13  Display Asto-Azimuth Residuals               "     "     "     "
14-14  Display GPS Residuals                        "     "     "     "
15-15  Display Constrained Residuals                "     "     "     "
16-16  Display Residuals Grouped Around
```

	Intersection Stations	"	"	"	"
17-17	Display Position Shifts	"	"	"	"
18-18	Display Googe Numbers	"	"	"	"
19-19	Display the Observational Summary	"	"	"	"
20-20	Display the Adjusted Positions	"	"	"	"
21-80	Reserved				

Accuracy Computation Record

01-02	QQ	
03-10	Reserved	
11-13	Station Serial Number, required	(integer)
14-50	Reserved	
51-53	Station Serial Number, required	(integer)
54-80	Reserved	

GPS Rotation Parameter Record

01-02	RR	
03-04	Reserved	
05-08	Start Year, default 1801	(integer)
09-10	Start Month, default 01	(integer)
11-12	Start Day, default 01	(integer)
13-14	Start Hour, default 00	(integer)
15-16	Start Minute, default 00	(integer)
17-17	Time Code, Start Time, default Z	
18-21	End Year, default 2100	(integer)
22-23	End Month, default 12	(integer)
24-25	End Day, default 31	(integer)
26-27	End Hour, default 23	(integer)
28-29	End Minute, default 59	(integer)
30-30	Time Code, End Time, default Z	
31-80	Reserved	

Auxiliary Parameter Indicator and Constraint Record

01-02	SS	
03-04	Observation Type 25 -- GPS (scale) 40 -- Vertical Angle (refraction) 52 -- Reduced Distance (scale) 54 -- Reduced Long Line (scale)	
05-08	Start Year, default 1801	(integer)
09-10	Start Month, default 01	(integer)
11-12	Start Day, default 01	(integer)
13-14	Start Hour, default 00	(integer)
15-16	Start Minute, default 00	(integer)
17-17	Time Code, Start Time, default Z	
18-21	End Year, default 2100	(integer)
22-23	End Month, default 12	(integer)
24-25	End Day, default 31	(integer)
26-27	End Hour, default 23	(integer)
28-29	End Minute, default 59	(integer)
30-30	Time Code, End Time, default Z	
31-35	Scale value or refraction, units of 0.00000001 (0.01 ppm), default 0	(integer)
36-40	Std. Dev. of Scale, units of 0.01 ppm, default 100	(integer)

41-80 Reserved

Variance Factor Indicator & Constraint Record

01-02	VV		
03-04	Observation Type	20 -- Horizontal Direction 25 -- GPS 30 -- Horizontal Angle 40 -- Vertical Angle 52 -- Reduced Distance 54 -- Reduced Long Line 60 -- Laplace Azimuth	
05-08	Start Year, default 1801		(integer)
09-10	Start Month, default 01		(integer)
11-12	Start Day, default 01		(integer)
13-14	Start Hour, default 00		(integer)
15-16	Start Minute, default 00		(integer)
17-17	Time Code, Start Time, default Z		
18-21	End Year, default 2100		(integer)
22-23	End Month, default 12		(integer)
24-25	End Day, default 31		(integer)
26-27	End Hour, default 23		(integer)
28-29	End Minute, default 59		(integer)
30-30	Time Code, End Time, default Z		
31-35	Initial Estimate of Variance Factor, units of 0.01, default 100		(integer)
36-36	Absolute Constraint	Y -- Impose Constraint N -- Do NOT Constrain (default)	
37-80	Reserved		

Records may appear in any order in an AFILE, with two exceptions. If BB records exist, they must precede any occurrence of DD, SS, RR, or VV records. If DD records exist, they must precede any occurrence of SS, RR, or VV records. There are no restrictions on the order of SS, RR, or VV records, except that they must come after BB and DD records.

The Ellipsoid Parameter Record (AA) is used to select an ellipsoid. If this record is not present, then the adjustment will refer to the Geodetic Reference System of 1980 (GRS 80) ellipsoid. This is the reference ellipsoid used by the NAD 83 datum. If the user needs to compute an adjustment using the NAD 27 datum, the parameters for the Clarke 1866 ellipsoid are:

semimajor axis = 6378206.400
square of first eccentricity = 0.006768657997291

The Bypass Record (BB) is used to bypass different types of observations. If the record is not present, then the adjustment will not bypass types of observations.

> Notable exception: If a two-dimensional or a one-dimensional adjustment is selected (see the DD record), then certain types of observations are automatically bypassed, even if a Bypass Record (BB) is not included.

The Constrained Coordinate Record (CC) is used to constrain (or fix) any combination of a station's geodetic latitude, geodetic longitude and height. If this record is not present, then no coordinates will be constrained. This will result in a singular adjustment and premature termination. Therefore, at least one CC record should exist in any AFILE. (In fact, an AFILE may well contain only one record: a CC record).

The station serial number and the coordinate values do not possess default values; these fields must be completed to receive that constraint. If a two-dimensional adjustment is computed (see DD record), then the height field is ignored. If a one-dimensional adjustment is computed, then the geodetic latitude and geodetic longitude fields are ignored. In addition, the user can constrain only latitudes, longitudes, or heights in any combination (subject to the constraints proposed by the dimensionality of the adjustment). For example, one can constrain the latitude, but not the longitude or height, at a station by completing only the geodetic latitude field.

Please note, when a field (latitude, longitude or height) is to be constrained, that particular field must not be blank. For example, if the user needed to constrain a landmark to a height of zero, then the height field must contain zeros and not be blank.

The standard deviations of a constraint are optional, and possess default values of 0.1 mm. A standard deviation is ignored unless its associated constraint value is present.

The CC records are formatted such that the fields of the constraint values correspond to the fields of the Blue Book *80* records. This enables the user to retrieve coordinates from a data base or compute coordinates from other adjustments, quickly edit these coordinate records, and then use the new records as constraints.

The height constraint is considered to be an orthometric height constraint if the orthometric height of the station is being adjusted. (See HC record.) The height constraint is considered to be a geoid height constraint if the geoid height of the station is being adjusted. Therefore, if a one-dimensional or a three-dimensional adjustment is being computed, be sure to check that the values in the height constraint fields actually represent the type of height you wish constrained.

The Constrained Astronomic Azimuth Record (CA) is used to constrain a mark-to-mark azimuth relation. If this record is not present, then this constraint is not included. This record is ignored on a one-dimensional adjustment. (See DD record.) The station serial numbers are not optional. If the value of the azimuth constraint is not provided, the adjustment will use the initial values of the stations (from the *80* records) to compute the constraint value. If the user wishes to provide a constant value, do not apply the Laplace correction. The standard deviation of the constraint is optional.

The Constrained Distance Record (CD) is used to constrain a mark-to-mark distance relation. If this record is not present, then this constraint is not included. The station serial numbers are not optional. If the value of the distance constraint is not provided, the adjustment will use the initial values

of the stations (from the *80* records) to compute the constraint value. The standard deviation of the constraint is optional.

The Constrained Zenith Distance Record (CZ) is used to constrain a mark-to-mark zenith distance relation. If this record is not present then this constraint is not included. This record is ignored on a two-dimensional adjustment. (See DD record.) The station serial numbers are not optional. If the value of the zenith distance constraint is not provided, the adjustment will use the initial values of the stations (from the *80* and *84* records) to compute the constraint value. The standard deviation of the constraint is optional. If the user wishes to provide a particular value for a zenith distance constraint, then that value should not be contaminated by any possible refraction error.

The Constrained Height Difference Record (CH) constrains a height difference relation. If this record is not present, then this constraint is not included. This record is ignored on a two-dimensional adjustment. (See DD record.) The constraint is considered to be an orthometric height difference if both endpoints adjust their orthometric heights. (See HC record.) The constraint is considered to be a geoid height difference if both endpoints adjust their geoid heights. The constraint is considered to be an ellipsoidal height difference if one endpoint adjusts its orthometric height while the other endpoint adjusts its geoid height. The station serial numbers are not optional. If the value of the height difference constraint is not provided, the adjustment will use initial values of the stations (from the *80* and *84* records) to compute the constraint value. The standard deviation of the constraint is optional.

The Dimensionality Record (DD) is used to select the dimensionality of the adjustment. If this record is not included, a three-dimensional adjustment is computed. If a two-dimensional adjustment is selected, then zenith distances and zenith distance constraints are automatically bypassed, and the height coordinate for each station is automatically held fixed at its initial value. If a one-dimensional adjustment is selected, then the directions, angles, astronomic azimuths, and azimuth constraints are automatically bypassed, and the geodetic latitude and geodetic longitude for each station are held fixed at their initial value. The user can always request additional types of observations to be bypassed by use of a BB record. A DD record should not be placed ahead of a BB record. SS, RR, and VV records should not be placed ahead of a DD record. The Default Mean Sea Level Record (EE) is used to specify a default value for the orthometric height of each station. If this record is not present, zero is used for the default value of the orthometric height. In practice, the user will always have an orthometric height present in the *80* records, so these values will override the default orthometric height.

The Default Geoid Height Record (GG) is used to specify a default value for the geoid height of each station. If this record is not present, zero is used for the default value of the geoid height. Values of the geoid height in the *84* records will override the default geoid height. If the user does not have an *84* record for some stations, then this record can easily be used to indicate an approximate geoid height for the project.

The Default Height Adjustment Record (HD) is used to select whether the orthometric heights or the geoid heights of the stations are adjusted. If this record is not present, the orthometric heights will be adjusted. This record is

ignored if a two-dimensional adjustment is being performed. The Control Point Height Adjustment Record (HC) is used to select whether the orthometric height or the geoid height of a particular station is adjusted. If this record is not present, the adjustment will use the default command selected in the HD record. The HC record is ignored if a two-dimensional adjustment is being performed.

In a typical situation the user wants to adjust orthometric heights, but certain stations may be bench marks. A decision may be made to include HC records for the bench marks, using the "G" indicator to refine estimates of the geoid height in the region. These improved geoid heights could then be included in a later adjustment using the "GG" or *84* records.

The Iteration Record (II) is used to control the iteration and misclosure display of the adjustment. If this record is not present, the default actions specified in table 2.2 are taken. If the adjustment cycles past the maximum number of iterations, or if a misclosure exceeds the specified limit, a termination flag is raised. However, the user can still request that statistics be displayed when the termination condition has occurred. The misclosure limits are defined in units of standard deviation. Note, for example, if a particular distance has a standard deviation of 1.5 cm and the computed minus the observed distance is 25 sigma, the actual misclosure for that particular distance is 37.5 cm. (Misclosure equals sigma units multiplied by the standard deviation.)

If the user does not have good preliminary coordinates, the size of the maximum allowed misclosure and of the minimum printed misclosure may be increased. This will prevent a premature termination due to bad starting coordinates. The large misclosures will decrease as the coordinates are improved. If blunders are present in the data, they could cause the adjustment to diverge, and thereby exceed the maximum number of iterations. Misclosures would "disappear" around the poor preliminary coordinates and "appear" around the blunders. Even if the iteration limit were exceeded, the user would probably wish to see the statistics displayed to help locate those problems.

The Adjustment Mode Record (MM) is used to select the mode of operation. If this record is not present, the default actions specified in table 2.2 are taken. The modes are arranged in order of increasing computational time. Mode one displays residuals scaled relative to the standard deviation of the observation (quasi-normalized residuals). These quasi-normalized residuals sometimes give an erroneous indication of which observation contains a blunder. Mode two also displays quasi-normalized residuals and computes a partial, sparse inverse to allow the display of coordinate standard deviations and accuracy computations. Mode three computes residuals scaled relative to the standard deviation of the residual (normalized residual). Normalized residuals can be used much more successfully in locating outliers. If any VV records are used, then mode three is automatically invoked.

Mode zero is a special simulation mode. In this mode, observations and their standard deviations are used to compute network statistics using linear error propagation. The observation values themselves are ignored, and need not be coded. This mode is provided to evaluate network designs before field operations commence.

The postadjustment indicator can be used to scale all of the error propagation statistics by the a posteriori variance of unit weight. This indicator should

not be used unless the observational data are of one type, and there is poor knowledge of the observation weights. It is not recommended that this indicator be used unless one is sure that blunders have been eliminated, that no systematic errors are present, that one does not have good initial estimates of the observation standard deviations, and that a chi-square statistical test indicates the a posteriori estimate is significantly different than 1.0. This option is automatically disabled when computing a simulation (mode = 0).

It is also possible to request that a new copy of the input Blue Book file be created where the *80* and *84* records are updated with new adjusted values. This file will be named "NEWBB" unless a different file name is specified. The creation of a new Blue Book is disabled when computing a simulation (mode = 0).

The Print Output Record (PP) is used to control the amount of printed output. If this record is not present, then the maximum amount of printing is generated. The specifications in table 2.2 detail exactly what output is controlled by this record. Typically, an output section is generated unless a nonblank character appears in an appropriate column. The criteria for residual output are based on the magnitude of the normalized (or quasi-normalized) residual. The default value, 0, displays all residuals. A number such as 300 displays only those normalized residuals greater than 30.0. If a simulation is being computed (mode = 0 in the MM record), then coordinate shifts will not be computed or displayed.

The Accuracy Computation Record (QQ) is used to compute relative accuracy statistics between selected stations. If this record is not present, then these computations will not be performed. The station serial numbers are not optional. These computations can help to locate weaknesses in the network and to determine the provisional accuracy classification of the survey.

The GPS Rotation Parameter Record (RR) is used to allocate extra parameters (unknowns) to the adjustment. If this record is not present, then no extra rotation parameters will be allocated. An RR record should not be placed ahead of a BB or DD record.

These parameters are defined according to time span. The default time span ranges from the years 1801 through 2100. The time codes are identical to those found in the Blue Book. While it is possible to wholly contain one or more time spans within a longer time span (i.e., "nested" time spans), a user will probably seldom need to allocate parameters in this way.

The Auxiliary Parameter Indicator and Constraint Record (SS) is used to compensate for systematic errors, due to refraction or scale error by assigning extra parameters (unknowns) to the adjustment. If this record is not present, then no extra parameters will be included. An SS record should not be placed ahead of a BB or DD record.

The parameters are defined according to observation type and time span. The observation type is not optional. A refraction parameter is created for zenith distances, and a scale parameter is created for other observation types. The default time span ranges from the years 1801 through 2100. The time codes are identical to those found in the Blue Book. Time spans are not allowed to overlap for a given observation type. It is possible to wholly contain one or more shorter time spans within a longer time span (that is, "nested" time

spans). However, the user would probably seldom have a need to assign parameters in this fashion.

With prior knowledge of the scale error or refraction, perhaps due to an earlier adjustment or a base line calibration, the user can apply this information as a constraint. The constraint is created if the parameter value and/or standard deviation is coded. No constraint is created if both fields are left blank.

Indiscriminate assignment of auxiliary parameters will weaken a survey project, perhaps to the point of giving a singular solution. Survey redundancy and multiple connections to the control network are encouraged if auxiliary parameters need to be part of the adjustment solution.

The Variance Factor Indicator and Constraint Record (VV) is used to readjust observation weights along with the coordinates. If this record is not present, then no weight rescaling will take place. The VV record should not be placed ahead of a BB or DD record. The variance factor is a term which multiplies the square of the standard deviation of an observation. Therefore, if the standard deviation is 3 cm and the variance factor is 4, then the rescaled standard deviation would become 6 cm. Use of this record will automatically invoke a mode 3 adjustment (see MM record) and require significant computation time.

The variance factors are defined according to observation type and time span. The observation type is not optional. The default time span ranges from the years 1801 through 2100. The time codes are identical to those found in the Blue Book. Time spans are not allowed to overlap for a given observation type. It is possible to wholly contain one or more shorter time spans within a longer time span (that is, "nested" time spans). However, variance factors would seldom need to be assigned in this fashion.

If the user has prior knowledge of a variance factor, perhaps due to an earlier adjustment, then this knowledge can be applied as a constraint. This is done by coding the absolute constraint field, using it as a mechanism to rescale standard deviations without editing every observation record in the Blue Book. Do not attempt to estimate variance factors without redundant measurements of the appropriate observation type. For example, it is impossible to compute the variance factor for the single distance measurement in a spur traverse.

To compute a variance factor ratio (FGCC 1984) for a particular observation type, first obtain a variance factor estimate from knowledge of standard deviation or from a minimally constrained, mode 3 adjustment of the survey. Then combine the survey data with the surrounding network data, and compute a much larger, minimally constrained adjustment. However, in this combined adjustment, the user would estimate variance factors for the survey observation types. The output would display the final estimates of the survey variances, the initial estimates, and the variance factor ratio. When this ratio exceeds 1.5, systematic error between the survey and the network is usually the cause. Both the survey data and the network data should be inspected. The estimate of the variance factor ratio becomes more reliable as the number of survey connections to the network is increased.

Error Messages

Error messages generated by ADJUST fall into two categories, anticipated error messages and programmer error messages. Anticipated error message are those which describe the various error conditions that occur due to incorrect formats, singular solutions, insufficient memory, etc. These messages and their diagnoses are described in tables 2.3 and 2.4, respectively.

Programmer error messages locate errors in the program logic and operation. These messages should never be encountered and invariably result in an immediate termination. If any programmer error message occurs in table 2.5, please contact the National Geodetic Survey, NOS, NOAA.

Table 2.3.--Anticipated error messages

1. No AFILE--All defaults active
2. *********Note: Semimajor axis = nnn
3. *********Note: Eccentricity = nnn
4. ***Warning: Negative VTPV
5. Slowly converging solution
6. Slowly converging variance factor solution
7. nnn ***Large misclosure
8. nnn Double precision words is too small for nnn parameters
9. nnn D.P. words less than nnn needed for rank=nnn insufficient storage--fatal!
10. Insufficient storage for constrained astro. azimuth
11. Insufficient storage for constrained zenith distances
12. Insufficient storage for constrained distances
13. Insufficient storage for constrained height distances
14. Insufficient storage for accuracy computations
15. Insufficient storage for hor. directions
16. Insufficient storage for hor. angles
17. Insufficient storage for zenith distances
18. Insufficient storage for reduced distances
19. Insufficient storage for Laplace azimuths
20. Insufficient memory for GPS vectors nnn
21. *** Illegal adjustment file format type--(AFILE record)
22. The BB record must precede the SS and VV records
23. Illegal dimension--(AFILE record)
24. Auxiliary parameter table overflowed--record ignored
25. Duplicates the nnn-th aux. parameter record
26. Illegal observational type
27. Variance factor table overflowed--record ignored
28. Duplicates the nnn-th variance factor record
29. No *80* control point records encountered--fatal
30. No Blue Book found--fatal error
31. nnn is illegal SSN--fatal
32. nnn duplicates the nnn-th entry--fatal
33. Over 700 landmarks
34. No *80* records for--(Blue Book record)
35. (Blue Book record) nnn is illegal SSN--fatal
36. (Blue Book record) nnn duplicates the nnn entry--fatal
37. Illegal time code--(time code)

38. Illegal azimuth degrees = nnn
39. (G-Format record) NVEC=nnn exceeds MAXVEC=nnn
40. Too many C records, bad G-file structure, (G-Format record)
41. Bad G-file structure--(card merge)
42. Illegal correlation--nnn, nnn
43. Bad correlation index nnn
44. *** warning--diagonal correlation nnn, nnn
45. Correlation matrix singularity--nnn
46. Terminated due to misclosures (C-O)/SD exceeding
47. nnn FDF=nnn **** is singular ********
48. Terminated due to variance factor singularities
49. The following nnn unknowns fall below tolerance of nnn
50. nnn (station name) North/south shift googe number is nnn
51. nnn (station name) East/west shift Googe number is nnn
52. nnn (station name) Up/down shift Googe number is nnn
53. nnn the nnn -th aux. parm. Googe number is nnn
54. nnn the nnn -th rot. parm. Googe number is nnn for list # nnn, at nnn (station name)
55. The adjustment is singular !!
56. ***** fatal--undetermined (U) stations *****
57. Updated control point records in file--(file name)
58. No old Blue Book found.
59. Not able to open new Blue Book file
60. Fatal error flag due to previous errors
61. The number of vectors in a group = nnn has exceeded the maximum allocated = nnn
62. The BB record must precede the DD, SS, RR, and VV records
63. GPS rotation parameter table overflowed--record ignored
64. Duplicate the nnn-th GPS rotation parameter record
65. The x component of the nnn-th aux. GPS rot. param. Googe number is nnn
66. The y component of the nnn-th aux. GPS rot. param. Googe number is nnn
67. The z component of the nnn-th aux. GPS rot. param. Googe number is nnn

---

Table 2.4--Diagnosis of data messages

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1. Check filename and job control used to execute ADJUST
2. Confirm this is the desired semimajor axis
3. Confirm this is the desired eccentricity squared
4. Check for large misclosures or blunders in the observational data
5. Check for large misclosures. May need to increase maximum number of iterations.
6. Variance factor solutions are not always rapidly convergent. Increase maximum number of iterations.
7. Check record book, possibly reject the observation by placing an "R" in column 6 of the Blue Book or an "R" in column 58 on the C record in the GPS data Transfer G-Format.
8. Increase the internal program storage of ADJUST. (See "Modifying the Memory Allocation" in sec. 4.)
9. Same as No. 8
10. Same as No. 8
11. Same as No. 8
12. Same as No. 8

13. Same as No. 8
14. Same as No. 8
15. Same as No. 8
16. Same as No. 8
17. Same as No. 8
18. Same as No. 8
19. Same as No. 8
20. Same as No. 8
21. Check the AFILE format record type
22. Place all DD, SS, and VV records after the BB record in AFILE
23. Check the DD record in AFILE. Only 1, 2, or 3 is allowed.
24. Either request fewer auxiliary parameters or increase internal arrays. (See "Modifying the Memory Allocation" in sec. 4.)
25. Check duplication. Auxiliary parameter time spans may not overlap for a given observation type.
26. Check observational record type. Refer to Blue Book specifications.
27. Either request fewer variance factors or increase internal arrays. (See "Modifying the Memory Allocation" in sec. 4.)
28. Check duplication. Variance factor time spans may not overlap for a given observation type.
29. Check for *80* Control Point records in Blue Book. Run MODBB to convert *81* records into *80*
30. Check filename and job control used to execute ADJUST
31. Check the Station Serial number. May only range from 001 through 999.
32. Each Station Serial Number on the *80* control point records in the Blue Book must be unique.
33. Increase internal arrays. (See "Modifying the Memory Allocation" in sec. 4.)
34. Check the Station Serial Number on the record and the *80* Control Point records in Blue Book.
35. Same as No. 31
36. Check the Station Serial Number and the list number of record type in Blue Book.
37. Check time code on record. Must correspond to table 2.3 in the Blue Book.
38. Check the azimuth on the *60* Laplace Azimuth record in Blue Book.
39. Need to increase internal arrays. (See "Modifying the Memory Allocation" in sec. 4.)
40. Check the GPS data transfer G-Format structure.
41. Same as No. 40
42. Check the correlation, permissible range between -1.0 and +1.0
43. Check the correlation index specifications in the Blue Book
44. Diagonal correlations are always 1.0. A 1.0 is substituted. May need to check the correlation indices.
45. The correlation/covariance matrix of the GPS vectors must never be singular. This message can occur if a redundant (trivial) set of GPS vectors have been created from GPS reduction software.
46. Verify observation, increase maximum allowable misclosure on II record in AFILE or possibly reject observation by editing an "R" in column 6 in Blue Book or a "R" in column 58 on the C record in GFILE.
47. Insufficient redundancy to estimate this variance factor. Obtain more observations.
48. Companion message to No. 47 or delete the VV record
49. Singular system. Check the network geometry and the line

identification.

50. May need to constrain the latitude using the CC record in the AFILE
51. May need to constrain the longitude using the CC record in the AFILE
52. May need to constrain the height using the CC record in AFILE
53. Check the network geometry. Increased redundancy is necessary when allocating auxiliary parameters.
54. Loose triangle. Check all the list of directions of the standpoint station for the connectivity of each list. May need to combine two lists.
55. Companion message to No. 49
56. Verify network geometry. Check dimensionality or possibly constrain stations using the CC record in AFILE.
57. Verify file
58. Same as No. 30
59. Check if newly selected Blue Book filename conflicts with existing filename
60. Refer to previous error messages
61. Increase the parameter NVEC in all of the parameter statements.
62. Place BB record ahead of DD, SS, RR, and VV records
63. Either request fewer GPS rotation parameters or increase internal arrays. See "Modifying the Memory Allocation" in sec. 4.)
64. Check duplication. GPS rotation parameter time spans may not overlap.
65. Same as 53.
66. Same as 53.
67. Same as 53.

Table 2.5--Programmer messages

---

1. (AFILE record) *** Record not in parameter table
2. Illegal IVF=nnn for N=nnn for OBS#
3. Illegal IVF=nnn for N=nnn in BIGL
4. Fatal error in Googe computation in FINAL nnn
5. State error in inversion of VFCVRG
6. State error in VFCVRG
7. Profile error in VFCVRG
8. State error in prop of VFGPS
9. Profile error in prop of VFGPS
10. Error in GETGIC--nnn
11. GPS index overflow in PUTICM
12. Illegal values in FORMIC=nnn
13. Illegal kind in FORMC=nnn
14. ********* Illegal IVF=nnn for N=nnn in FIXVF
15. Premature file end in FORMG--NVEC=nnn
16. Illegal kind in COMPOB=nnn
17. Illegal values in IUNSTA nnn
18. Illegal values in IUNAUX nnn
19. Illegal values in IUNROT: IZ=nnn NZ=nnn
20. Illegal value in INVIUN nnn
21. Illegal values in IUNSHF nnn
22. Profile error in NORMAL
23. Accum error in NORMAL

24. Fatal Googe error in NORMAL nnn
25. HOG state error in NORMAL
26. Premature file end in NORMAL--NVEC=nnn
27. Illegal type code nnn
28. Illegal icode in SINGUL nnn
29. Programmer error in CONVRG
39. Illegal parameter code in CONVRG--nnn
31. Basement window error--nnn
32. Fatal error in Googe computation in FINAL nnn
33. State error in FINAL
34. SSN table error in OBSSUM--nnn
35. Illegal IVF=nnn for N=nnn in ROBS
36. System not inverted in ROBS
37. All convariance elements not within profile--ROBS
38. Illegal kind in ROBS--nnn
39. Premature file end in RGPS--NVEC=nnn
40. State error in first prop of GPSSDV
41. Profile error in first prop of GPSSDV
42. Illegal IVF=nnn for N=nnn in GPSSDV
43. State error in PROPCV of GPSSDV
44. Profile error in PROPCV of GPSSDV
45. State error in second prop of GPSSDV
46. Profile error in second prop of GPSSDV
47. Get sigma error in ADJAUX--nnn
48. Illegal IVF=nnn for N=nnn in RESID2
49. System not inverted in RESID2
50. All convariance elements not within profile--nnn
51. Illegal kind in RESID2--nnn
52. Premature file end in RESID2--NVEC=nnn
53. Premature file end in DUMRD -- NVEC=nnn
54. SSN table error in ADJPOS--nnn
55. Get sigma error in ADJPOS--nnn
56. Illegal ISN in UP80--nnn
57. Illegal ISN in UP84--nnn
58. State error in RELACC
59. Profile error in RELACC
60. ****illegal ISN nnn for NSTA=nnn in PUTALA
61. ****illegal ISN nnn for NSTA=nnn in PUTALO
62. ****illegal ISN nnn for NSTA=nnn in PUTGLA
63. ****illegal ISN nnn for NSTA=nnn in PUTGLO
64. ****illegal ISN nnn for NSTA=nnn in PUTECX
65. ****illegal ISN nnn for NSTA=nnn in PUTECY
66. ****illegal ISN nnn for NSTA=nnn in PUTECZ
67. ****illegal ISN nnn for NSTA=nnn in PUTMSL
68. ****illegal ISN nnn for NSTA=nnn in PUTGH
69. ****illegal IAUX nnn for NAUX=nnn in PUTAUX
70. ****illegal IZ nnn for NZ=nnn in PUTROT
71. ****illegal ISN nnn for NSTA=nnn in GETALA
72. ****illegal ISN nnn for NSTA=nnn in GETALO
73. ****illegal ISN nnn for NSTA=nnn in GETGLA
74. ****illegal ISN nnn for NSTA=nnn in GETGLO
75. ****illegal ISN nnn for NSTA=nnn in GETECX
76. ****illegal ISN nnn for NSTA=nnn in GETECY
77. ****illegal ISN nnn for NSTA=nnn in GETECZ

78. ****illegal ISN nnn for NSTA=nnn in GETMSL
79. ****illegal ISN nnn for NSTA=nnn in GETGH
80. ****illegal IAUX nnn for NAUX=nnn in GETAUX
81. ****illegal IZ nnn for NZ=nnn in GETROT
82. Get sigma error in ADJGRT
83. Illegal IGRT = nnn for NGRT = nnn in PUTGRT
84. Illegal IGRT = nnn for NGRT = nnn in GETGRT

---

3. MATHEMATICAL MODELS

This section covers various coordinate systems and the mathematical models (observation equations) used by program ADJUST. These mathematical models include the least squares adjustment models, observation models, correlations, and variance models.

Coordinate Systems

The default ellipsoid used by ADJUST is the Geodetic Reference System, GRS 1980. However, in principle, an ellipsoid is not needed for performing an adjustment in three dimensions. ADJUST is a computer program used for adjusting points (stations) in space using a local geodetic horizon system. (See fig. 3.1.) ADJUST utilizes a local astronomic horizon system (LAHS) to set up the observation equations. The observation equation coefficients are then transformed into those appropriate for local geodetic horizon systems (LGHS). The differential shifts of coordinates are in linear units (meters) in a geodetic horizon system centered on the points in question; thus, there are as many local coordinate systems as there are stations.

When the surveyor observes horizontal or vertical theodolite observations in the field, the geodetic observation is not measured. Rather, the astronomical observation is measured (e.g., an astronomic azimuth is observed, not a geodetic azimuth). Therefore, an important relationship between coordinate systems is the one between the LAHS and the LGHS. (See fig. 3.2.) Instruments are aligned tangent to the plumb line (or the gravity vector), not to the ellipsoid normal. (See figs. 3.1 and 3.2.) Theory requires that the direction of gravity be known at all stations from which theodolite observations are measured. Because this is seldom achieved, some approximate values must be used for astronomic coordinates. These preliminary astronomic latitudes and longitudes are computed using the preliminary geodetic latitudes and longitudes and the deflections of the vertical. If the deflections are not present, ADJUST will set the deflections equal to zero; hence, the preliminary astronomic coordinates are set respectively to the most recent geodetic values. As a step in processing, ADJUST transforms the observation equations from the local astronomic horizon system to the local geodetic horizon system using rotation matrices (Steeves 1984; Vincenty 1979).

The LGHS and the LAHS do have similarities. Both reference systems are three-dimensional Cartesian systems with their origins at the point (station) in question. However, their axes are different whenever the deflection of the vertical is known to be nonzero. For the LGHS and the LAHS, we will refer to their axes as (x,y,z) and (u,v,w), respectively. The LGHS has a z-axis that is coincident with the ellipsoid normal at the station and is positive upwards.

The LGHS x-axis points to the geodetic north and the y-axis points to the geodetic east. The w-axis of the LAHS is coincident with the gravity vector at

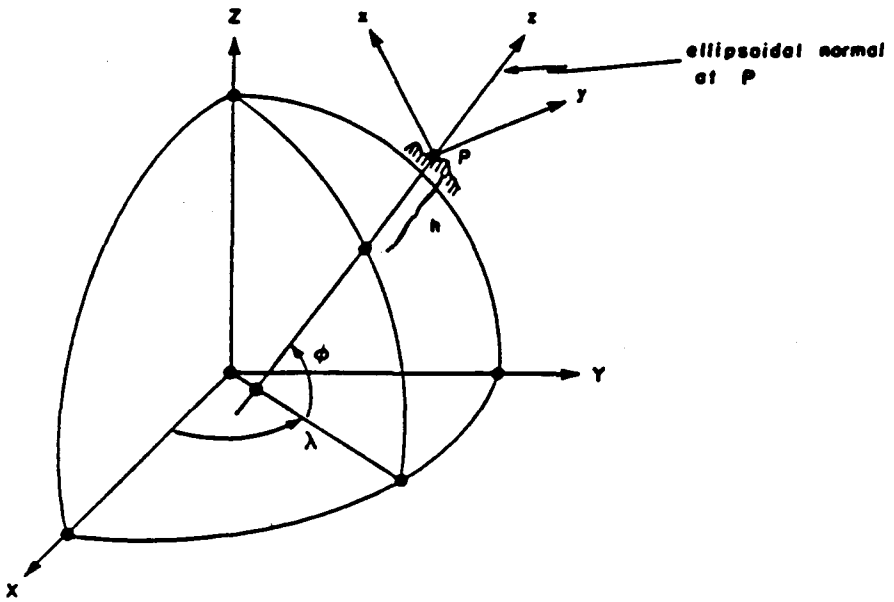

Figure 3.1.--Local geodetic horizon system (Steeves 1984)

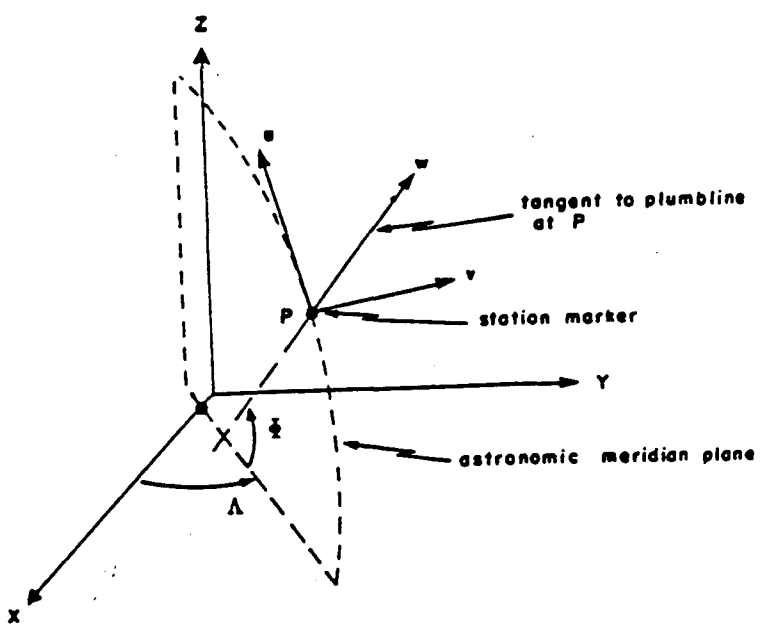

Figure 3.2.--Local astronomic horizon system (Steeves 1984)

the station and is positive upwards. The u-axis points to the astronomic north while the v-axis points to the astronomic east.

The relationship between the LGHS and LAHS is defined by:

$$(x,\ y,\ z)^t = R(u,\ v,\ w)^t \tag{3.1}$$

where R is a rotation matrix which performs the transformation from the LAHS to the LGHS. Vincenty (1980: eq. 6) derives that

$$R = R_G R_A^T = \begin{bmatrix} 1 & \sin\Phi\cdot(\Lambda-\lambda) & (\Phi-\phi) \\ -\sin\Phi\cdot(\Lambda-\lambda) & 1 & \cos\Phi\cdot(\Lambda-\lambda) \\ -(\Phi-\phi) & -\cos\Phi\cdot(\Lambda-\lambda) & 1 \end{bmatrix} \tag{3.2}$$

where

$$R_G = \begin{bmatrix} -\sin\phi\ \cos\lambda & -\sin\phi\ \sin\lambda & \cos\phi \\ -\sin\lambda & \cos\lambda & 0 \\ \cos\phi\ \cos\lambda & \cos\phi\ \sin\lambda & \sin\phi \end{bmatrix} \tag{3.3}$$

and

$$R_A = \begin{bmatrix} -\sin\Phi\ \cos\Lambda & -\sin\Phi\ \sin\Lambda & \cos\Phi \\ -\sin\Lambda & \cos\Lambda & 0 \\ \cos\Phi\ \cos\Lambda & \cos\Phi\ \sin\Lambda & \sin\Phi \end{bmatrix} \tag{3.4}$$

where $(\phi,\ \lambda)$ are the geodetic latitude and longitude and $(\Phi,\ \Lambda)$ are the astronomic latitude and longitude.

Equation (3.1) can also be written as

$$\begin{aligned} x &= u + m\cdot v + l\cdot w \\ y &= v - m\cdot u + n\cdot w \\ z &= w - l\cdot u - n\cdot v \end{aligned} \tag{3.5}$$

where

$$\begin{aligned} m &= \sin\Phi \cdot (\Lambda - \lambda) \\ n &= \cos\Phi \cdot (\Lambda - \lambda) \\ l &= \Phi - \phi \end{aligned}$$

The Least Squares Problem

The least squares problem is minimize

$$Q(X) = V(X)^t \, \Sigma_{L_b}^{-1} \, V(X) \tag{3.6}$$

where V(X) is a residual function (Dennis and Schnabel 1983). Consider the method of observation equations (Mikhail 1976 or Uotila 1967)

$$L_a = F\,(X_a) \tag{3.7}$$

where L_a is a vector of computed observation values of length n, X is a vector of model parameters of length u, and F is a vector of functions that is a theoretical model which describes the observations in terms of the parameters.

In this method

$$V\,(X) = F\,(X_a) - L_b \tag{3.8}$$

where L_b is the vector of actual observations.

Assume model $F(X_a)$ is not strongly nonlinear and the problem is a small residual one. These simplifying assumptions allow selection of the Gauss-Newton method of solution.

The design matrix, A, is defined as

$$A = \left.\frac{\partial F}{\partial X_a}\right|_{X_a = X_o} \tag{3.9}$$

where A is a matrix of differential changes in the observation model with respect to the parameters, X_a, evaluated at a particular set of parameter values, X_o. A vector of observation misclosures is

$$L = L_b - L_a \tag{3.10}$$

where L_b and L_a are described above.

Associated with the observation vector L_b is a symmetric variance-covariance matrix Σ_{L_b}, which contains information on observation precision and correlation.

The <u>observation equation</u> may be written as

$$AX = L + V \tag{3.11}$$

where V is a vector of residual errors and X is a vector of corrections to the parameter vector X_a. The least squares estimate of X is

$$X = (A^t \Sigma_{L_b}^{-1} A)^{-1} A^t \Sigma_{L_b}^{-1} L . \tag{3.12}$$

This is a solution of the <u>normal equations</u>

$$NX = U \tag{3.13}$$

where the matrix of normal equation coefficients is

$$N = A^t \Sigma_{L_b}^{-1} A \tag{3.14}$$

and the right hand vector is

$$U = A^t \Sigma_{L_b}^{-1} L . \tag{3.15}$$

One technique for solution is to compute a Cholesky decomposition of the normal matrix, N,

$$NX = R^t RX = U. \tag{3.16}$$

The estimate of X provides a new set of values for our parameters by replacing

$$X_a + X \rightarrow X_a. \tag{3.17}$$

If the observation model $F(X_a)$ is nonlinear (that is, A is not constant for any set of X_a), then the entire process starting with eq. (3.6), must be iterated until the vector X_a reaches a stationary point.

Estimates of parameter precision and correlations are given by the adjusted parameter variance-covariance matrix, Σ_{x_a}. This matrix is computed by

$$\Sigma_{x_a} = (A^t \Sigma_{L_b}^{-1} A)^{-1} . \tag{3.18}$$

Of course, this matrix can always be scaled by an estimated variance of unit weight, if such an estimate is felt valid. The user may also compute the

precision of any other quantity which can be derived from the parameters. Suppose one wishes to compute a vector of quantities, S,

$$S = S\ (X_a) \tag{3.19}$$

from the adjusted parameters, X_a. A geometry matrix, G, is defined as

$$G = \frac{\partial S}{\partial X_a} \bigg|_{X_a = X_o} \tag{3.20}$$

where G is a matrix of differential changes in the functions, S, with respect to the parameters, X_a, evaluated at a particular set of parameter values, X_o.

By the principle of linear error propagation,

$$\Sigma = G\ \Sigma_{x_a}\ G^t \tag{3.21}$$

or

$$\Sigma_s = G(A^t\ \Sigma_{L_b}^{-1}\ A)^{-1}\ G^t \tag{3.22}$$

where Σ_s is the variance-covariance matrix of the computed quantities. This last equation is useful since its terms are quantities derivable from the parameters. It could be used, for example, to compute Σ_v or Σ_{L_a}.

Another useful quantity is the correlation coefficient ρ, where

$$\rho = \frac{\sigma_{ij}}{\sigma_{ii}\sigma_{jj}} \tag{3.23}$$

and σ_{ij} is the value in the i-th row and j-th column of the adjusted parameter variance-covariance matrix, Σ_{x_a}. These correlations can be thought of as a normalized covariance, since

$$-1 \leq \rho \leq 1\ . \tag{3.24}$$

Correlations between parameters that approach +1 indicate ill-conditioning of the system.

Several sparse matrix packages have been introduced by various authors, George and Liu (1981), Dillinger (1981) and Milbert (1984). Each of these packages

was written to handle large adjustments by treating each observation equation (eq. 3.11) as independent and accumulating partial normal equations as

$$N + (1/\sigma_i^2)\ A_i^t\ A_i \rightarrow N, \tag{3.25}$$

where A_i is the row of matrix A corresponding to the i-th equation. In order to exploit such software for correlated observations (eg., GPS vectors), a transformation must be applied to matrix A and vector L,

$$\begin{aligned} A' &= R^{-t}\ A \\ L' &= R^{-t}\ L \end{aligned} \tag{3.26}$$

where the prime notation denotes a result in a different vector space, and where

$$\Sigma_{L_b} = R^t\ R \tag{3.27}$$

and

$$R^{-t} = (R^{-1})^t\ . \tag{3.28}$$

That is, the rows of A and the associated elements of L which correspond to correlated observations are transformed using the Cholesky factor of the covariance matrix. These transformed observation equations are then accumulated into the normal equations. This observation decorrelation method is further described by Milbert (1985a).

Mathematical Models

For the discussion on mathematical models, the reader should refer to tables 3.1, 3.2, and 3.3. Since most of the symbols, figures, formulas, and mathematical models are identical to the three-dimensional adjustment program HAVAGO in the NOAA Technical Memorandum NOS NGS-17 (Vincenty 1979), similar tables can also be found in that memorandum. Table 3.1 defines the symbols used in the equations; table 3.2 gives various conversions and inverse formulas in space; and table 3.3 lists the mathematical models of the different types of observations adjusted by program ADJUST. Figures 3.3, 3.4, and 3.5 can be examined in conjunction with table 3.2 and table 3.3 to help clarify the formulas found in these tables. The subsequent section shows how these equations are augmented by auxiliary unknowns.

With the formulas in table 3.3 the user can compute different kinds of mark-to-mark observations between stations. These formulas depend on the inverse formulas in space found in part b of table 3.2. Examining formulas (3.32) through (3.43), the reader does not find the application of any ellipsoid parameters (i.e., semimajor axis, semiminor axis, or the first eccentricity). The reason these ellipsoid parameters are not present is because we are adjusting points (stations) in space; we are not adjusting points to the ellipsoid. This is true whether or not we perform a one, two, or three-dimensional adjustment.

Table 3.1.--Symbols and definitions

a	Semimajor axis of the ellipsoid
b	Semiminor axis of the ellipsoid
e	First eccentricity of the ellipsoid
e'	Second eccentricity
M	Radius of curvature in the meridian
N	Radius of curvature in the prime vertical
ϕ	geodetic latitude, positive north
λ	Geodetic longitude, positive east
h	Geodetic height (height above ellipsoid)
Φ	Astronomic latitude
Λ	Astronomic longitude
H	Height above the geoid
A	Astronomic azimuth, clockwize from the north
V	Vertical angle, positive upward from the astronomic horizon
S	Spatial distance
XYZ	Right-handed, three-dimensional (Earth-centered fixed) Cartesian coordinate system whose Z-axis is defined by the Conventional International Origin (CIO), and the XZ plane is parallel to the Mean Greenwich Zero Meridian.
xyz	Right-handed, three-dimensional (local geodetic horizon system) Cartesian coordinate system whose z-axis is coincidental with the ellipsoid normal at station in question; x-axis points to geodetic north, and y-axis points to geodetic east.
uvw	Right-handed, three-dimensional (local astronomic horizon system) Cartesian coordinate system whose w-axis is coincident with the gravity vector at station in question; u-axis points to astronomic north and the v-axis points to astronomic east.

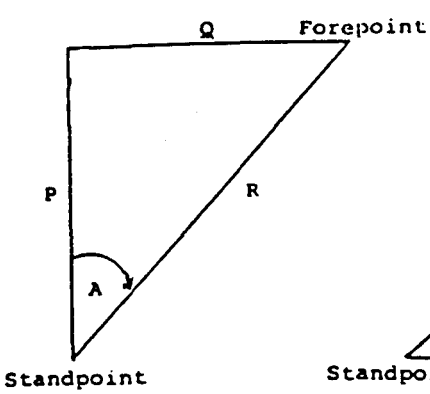

Figure 3.3.--Top view.

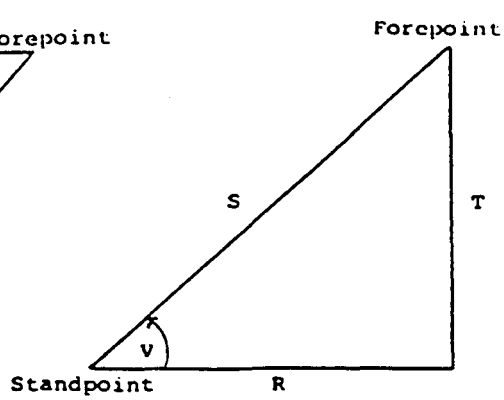

Figure 3.4.--Side view

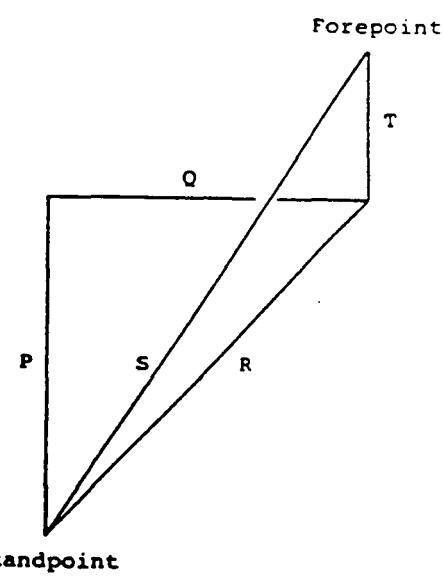

Figure 3.5.--Perspective view.

(excerpted from Vincenty 1979)

Table 3.2.--General equations

a. Conversion of (ϕ, λ, h) to (X, Y, Z)

$$X = (N+h)\cos\phi\cos\lambda \tag{3.29}$$

$$Y = (N+h)\cos\phi\sin\lambda \tag{3.30}$$

$$Z = [N(1-e^2) + h]\sin\phi \tag{3.31}$$

b. Components in the local astronomic horizon system. (See figs. 3.3, 3.4, and 3.5.)

$$\Delta X = X_2 - X_1 \tag{3.32}$$

$$\Delta Y = Y_2 - Y_1 \tag{3.33}$$

$$\Delta Z = Z_2 - Z_1 \tag{3.34}$$

$$P_1 = -\sin\Phi_1(\Delta X\cos\Lambda_1 + \Delta Y\sin\Lambda_1) + \Delta Z\cos\Phi_1 \tag{3.35}$$

$$Q_1 = -\Delta X\sin\Lambda_1 + \Delta Y\cos\Lambda_1 \tag{3.36}$$

$$R_1 = (P_1^2 + Q_1^2)^{1/2} \tag{3.37}$$

$$T_1 = \cos\Phi_1(\Delta X\cos\Lambda_1 + \Delta Y\sin\Lambda_1) + \Delta Z\sin\Phi_1 \tag{3.38}$$

$$S = (\Delta X^2 + \Delta Y^2 + \Delta Z^2)^{1/2} \tag{3.39}$$

Similarly, we have at point #2

$$P_2 = \sin\Phi_2\,(\Delta X\cos\Lambda_2 + \Delta Y\sin\Lambda_2) - \Delta Z\cos\Phi_2 \tag{3.40}$$

$$Q_2 = \Delta X\sin\Lambda_2 - \Delta Y\cos\Lambda_2 \tag{3.41}$$

$$R_2 = (P_2^2 + Q_2^2)^{1/2} \tag{3.42}$$

$$T_2 = -\cos\Phi_2\,(\Delta X\cos\Lambda_2 + \Delta Y\sin\Lambda_2) - \Delta Z\sin\Phi_2 \tag{3.43}$$

Table 3.3.--Mathematical models (mark-to-mark)

a. For GPS vectors:

$$\Delta X = X_2 - X_1$$

$$\Delta Y = Y_2 - Y_1 \tag{3.44}$$

$$\Delta Z = Z_2 - Z_1$$

b. For astronomic azimuths:

$$A_{12} = \arctan (Q_1/P_1) \tag{3.45}$$

c. For astronomic directions:

$$d_{12} = A_{12} - \Omega \tag{3.46}$$

where Ω is an orientation unknown for each independently measured set of directions.

d. For astronomic zenith distances:

$$ZD_{12} = \pi/2 - \arctan (T_1/R_1) \tag{3.47}$$

e. For mark-to-mark distances:

$$S = (\Delta X^2 + \Delta Y^2 + \Delta Z^2]^{1/2} \tag{3.48}$$

f. For astronomic horizontal angles:

$$HA_{1,23} = A_{13} - A_{12} \tag{3.49}$$

Table 3.4.--Observation equations (mark-to-mark)

---

a. GPS vectors:

$$V_{\Delta x} = a_1\, dx_1 + a_2\, dy_1 + a_3\, dz_1 + a_4\, dx_2 + a_5\, dy_2 + a_6\, dz_2 + K_{\Delta x} \tag{3.50}$$

$$V_{\Delta y} = b_1\, dx_1 + b_2\, dy_1 + b_3\, dz_1 + b_4\, dx_2 + b_5\, dy_2 + b_6\, dz_2 + K_{\Delta y} \tag{3.51}$$

$$V_{\Delta z} = c_1\, dx_1 + c_2\, dy_1 + c_3\, dz_1 + c_4\, dx_2 + c_5\, dy_2 + c_6 dz_2 + K_{\Delta z} \tag{3.52}$$

b. Azimuths:

$$V_a = d_1\, du_1 + d_2\, dv_1 + d_3\, dw_1 + d_4\, du_2 + d_5\, dv_2 + d_6\, dw_2 + K_a \tag{3.53}$$

c. Directions:

$$V_d = e_1\, du_1 + e_2\, dv_1 + e_3\, dw_1 + e_4\, du_2 + e_5\, dv_2 + e_6\, dw_2 + e_7\, \Omega + K_d \tag{3.54}$$

d. Zenith distances:

$$V_{ZD} = f_1\ du_1 + f_2\ dv_1 + f_3\ dw_1 + f_4\ du_2 + f_5\ dv_2 + f_6\ dw_2 + K_{ZD} \tag{3.55}$$

e. Distances:

$$V_s = g_1\ dx_1 + g_2\ dy_1 + g_3\ dz_1 + g_4\ dx_2 + g_5\ dy_2 + g_6\ dz_2 + K_s \tag{3.56}$$

f. Horizontal angles:

$$V_h = h_1\ du_1 + h_2\ dv_1 + h_3\ du_2 + h_4\ dv_2 + h_5\ du_3 + h_6\ dv_3 + K_h \tag{3.57}$$

Table 3.5.--Coefficients of observation equations

$$\begin{aligned}
a_1 &= R_G(1,1)_1 = \sin\phi_1 \cos\lambda_1 \\
a_2 &= R_G(2,1)_1 = \sin\lambda_1 \\
a_3 &= R_G(3,1)_1 = -\cos\phi_1 \cos\lambda_1 \\
a_4 &= R_G(1,1)_2 = -\sin\phi_2 \cos\lambda_2 \\
a_5 &= R_G(2,1)_2 = -\sin\lambda_2 \\
a_6 &= R_G(3,1)_2 = \cos\phi_2 \cos\lambda_2
\end{aligned} \tag{3.58}$$

$$\begin{aligned}
b_1 &= R_G(1,2)_1 = \sin\phi_1 \sin\lambda_1 \\
b_2 &= R_G(2,2)_1 = -\cos\lambda_1 \\
b_3 &= R_G(3,2)_1 = -\cos\phi_1 \sin\lambda_1 \\
b_4 &= R_G(1,2)_2 = -\sin\phi_2 \sin\lambda_2 \\
b_5 &= R_G(2,2)_2 = \cos\lambda_2 \\
b_6 &= R_G(3,2)_2 = \cos\phi_2 \sin\lambda_2
\end{aligned} \tag{3.59}$$

$$\begin{aligned}
c_1 &= R_G(1,3)_1 = -\cos\phi_1 \\
c_2 &= R_G(2,3)_1 = 0
\end{aligned}$$

$$c_3 = R_G(3,3)_1 = -\sin\phi_1$$

$$c_4 = R_G(1,3)_2 = \cos\phi_2 \tag{3.60}$$

$$c_5 = R_G(2,3)_2 = 0$$

$$c_6 = R_G(3,3)_2 = \sin\phi_2$$

$$d_1 = Q_1/R_1^2$$

$$d_2 = -P_1/R_1^2$$

$$d_3 = 0$$

$$d_4 = -[Q_1(\cos\phi_1 \cos\phi_2 + \sin\phi_1 \sin\phi_2 \cos\Delta\lambda) + P_1 \sin\phi_2 \sin\Delta\lambda]/R_1^2 \tag{3.61}$$

$$d_5 = (P_1 \cos\Delta\lambda - Q_1 \sin\phi_1 \sin\Delta\lambda)/R_1^2$$

$$d_6 = 0 \text{ (by approximation)}$$

$$e_1 = d_1$$

$$e_2 = d_2$$

$$e_3 = d_3$$

$$e_4 = d_4 \tag{3.62}$$

$$e_5 = d_5$$

$$e_6 = d_6$$

$$e_7 = -1.0$$

$$f_1 = -(P_1 T_1)/(R_1 S^2)$$

$$f_2 = -(Q_1 T_1)/(R_1 S^2)$$

$$f_3 = R_1/S^2$$

$$f_4 = -[-\cos\phi_1 \sin\phi_2 \cos\Delta\lambda + \sin\phi_1 \cos\phi_2 + (T_1 P_2/S^2)]/R_1 \tag{3.63}$$

$$f_5 = -[-\cos\phi_1 \sin\Delta\lambda + (T_1 Q_2/S^2)]/R_1$$

$$f_6 = -[\cos\phi_1 \cos\phi_2 \cos\Delta\lambda + \sin\phi_1 \sin\phi_2 + (T_1 T_2/S^2)]/R_1$$

$$g_1 = -P_1/S$$

$$g_2 = -Q_1/S$$

$$g_3 = -T_1/S$$

$$g_4 = -P_2/S \qquad (3.64)$$

$$g_5 = -Q_2/S$$

$$g_6 = -T_2/S$$

$$h_1 = d_1 \text{ (right)} - d_1 \text{ (left)}$$

$$h_2 = d_2 \text{ (right)} - d_2 \text{ (left)}$$

$$h_3 = -d_4 \text{ (left)}$$

$$h_4 = -d_5 \text{ (left)} \qquad (3.65)$$

$$h_5 = d_4 \text{ (right)}$$

$$h_6 = d_5 \text{ (right)}$$

Looking at eqs. (3.53), (3.54), (3.55), and (3.57), the reader notices that the differential shifts are in a local geodetic horizon (coordinate system). Respectively, $K_{\Delta x}$, $K_{\Delta y}$ and $K_{\Delta z}$ are the differences between the computed and observed GPS vectors (Δx, Δy and Δz). The observation equations for azimuths, directions, zenith distances, and horizontal angles are formed using local astronomic horizon differential shifts. After the coefficients for these observation equations (eqs. 3.53, 3.54, 3.55, and 3.57) are computed, ADJUST uses a rotation matrix (eq. 3.2) to transform the observation equations from an LAHS to the LGHS. Since the observation equation for mark-to-mark distances (eq. 3.56) contains the differential shifts in an LGHS, no transformation is required. Again, the last term (K_a, K_d, K_{ZD}, K_s, and K_h) on these observation eqs. (3.53 through 3.57) are the differences between the computed and the observed observations.

There is a slight dependence of the astronomic azimuths and directions on the vertical differential shift of the forepoint (target). However, following Vincenty (1979) we take the coefficients of the observation equations, d_6 and e_6 to be zero. Note that the observation models, (3.53) and (3.54), are still computed rigorously. In keeping with this approximation, the vertical differential shifts for the horizontal angle observation eq. (3.57) are suppressed.

All of the observation equations in table 3.4 are set for a three-dimensional adjustment. But ADJUST also has the capability for one- and two-dimensional adjustments. Since a one-dimensional adjustment will modify only the vertical component, only two coefficients are needed for the appropriate observation equations. These two coefficients are the vertical components of the standpoint and the forepoint. They are equal to the third and sixth coefficients of their

respective coefficients found in table 3.5. Likewise, when performing a two-dimensional adjustment, only the horizontal components will reflect shifts and the vertical components are held fixed. Hence, for a two-dimensional adjustment, only four coefficients are required. These four are for the horizontal components of the standpoint and the forepoint. Again, these four will equal the first, second, fourth, and fifth coefficients of their respective coefficients found in table 3.5. The unneeded coefficients are never formed nor accumulated into the normal equations.

Orientation Unknowns and Auxiliary Parameters

As mentioned previously, an orientation unknown (Ω) exists for each independently measured set of directions. These orientation unknowns are present only if ADJUST is performing a two- or three-dimensional adjustment containing direction observations.

In addition to orientation unknowns for horizontal directions, ADJUST can compute various types of auxiliary parameters (AP). These AP's can consist of GPS rotation unknowns, refraction unknowns for zenith distances, or scale unknowns for spatial distances and GPS vectors. Table 3.6 shows the modified observation models. Table 3.7 contains these additional coefficients which would be attached to the respective observation equation (table 3.4) when needed.

Table 3.6.--Modified observation models

a. GPS vectors (scale parameter = k)

$$\begin{aligned} \overline{\Delta X} &= \Delta X - k \cdot \Delta X \\ \overline{\Delta Y} &= \Delta X - k \cdot \Delta Y \\ \overline{\Delta Z} &= \Delta X - k \cdot \Delta Z \end{aligned} \tag{3.66}$$

b. GPS vectors (rotation parameters = $(\omega_x, \omega_y, \omega_z)$)
(by Rapp 1983: pp. 61-64, 138)

$$\begin{bmatrix} \overline{\Delta X} \\ \overline{\Delta Y} \\ \overline{\Delta Z} \end{bmatrix} = R_{G_0}^{t} R_{\omega} R_{G_0} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \tag{3.67}$$

where R_{G_0} is (3.3) evaluated at a mean point (ϕ_0, λ_0), and where

$$R_\omega = \begin{bmatrix} 1 & -\omega_z & \omega_y \\ \omega_z & 1 & -\omega_x \\ -\omega_y & \omega_x & 1 \end{bmatrix} \tag{3.68}$$

Thus,

$$\begin{aligned} \overline{\Delta X} &= \Delta X + \ell_1 \, \Delta Y + \ell_2 \, \Delta Z \\ \overline{\Delta Y} &= \Delta Y - \ell_1 \, \Delta X + \ell_3 \, \Delta Z \\ \overline{\Delta Z} &= \Delta Z - \ell_2 \, \Delta X - \ell_3 \, \Delta Y \end{aligned} \tag{3.69}$$

where

$$\begin{aligned} \ell_1 &= \cos \phi_0 \, \omega_x + \sin \phi_0 \, \omega_z \\ \ell_2 &= \sin \varphi_0 \sin \lambda_0 \, \omega_x - \cos \lambda_0 \, \omega_y - \cos \varphi_0 \sin \lambda_0 \, \omega_z \\ \ell_3 &= -\sin \varphi_0 \cos \lambda_0 \, \omega_x - \sin \lambda_0 \, \omega_y + \cos \phi_0 \cos \lambda_0 \, \omega_z \end{aligned} \tag{3.70}$$

c. Zenith distances (refraction parameter = k)
(by Rapp 1983: p. 149, eq. 56)

$$\overline{ZD}_{12} = ZD_{12} - k \cdot R_1 \tag{3.71}$$

d. Spatial distances (scale parameter = n)

$$\overline{S} = S - k \cdot S \tag{3.72}$$

Table 3.7.--Auxiliary parameter coefficients

---

a. For GPS vectors (scale):

$$a_7 = -(X_2 - X_1) \tag{3.73}$$

$$b_7 = -(Y_2 - Y_1) \tag{3.74}$$

$$c_7 = -(Z_2 - Z_1) \tag{3.75}$$

b. For GPS vectors (rotations about (x,y,z) axes at (ϕ_0, λ_0))

$$a_8 = -\cos\phi_0 (Y_2 - Y_1) - \sin\phi_0 \sin\lambda_0 (Z_2 - Z_1)$$

$$a_9 = \cos\lambda_0 (Z_2 - Z_1)$$

$$a_{10} = -\sin\phi_0 (Y_2 - Y_1) + \cos\phi_0 \sin\lambda_0 (Z_2 - Z_1)$$

$$b_8 = \cos\phi_0 (X_2 - X_1) + \sin\phi_0 \cos\lambda_0 (Z_2 - Z_1)$$

$$b_9 = \sin\lambda_0 (Z_2 - Z_1)$$

$$b_{10} = \sin\phi_0 (X_2 - X_1) - \cos\phi_0 \cos\lambda_0 (Z_2 - Z_1)$$

$$c_8 = \sin\phi_0 \sin\lambda_0 (X_2 - X_1) - \sin\phi_0 \cos\lambda_0 (Y_2 - Y_1)$$

$$c_9 = -\cos\lambda_0 (X_2 - X_1) - \sin\lambda_0 (Y_2 - Y_1)$$

$$c_{10} = -\cos\phi_0 \sin\lambda_0 (X_2 - X_1) + \cos\phi_0 \cos\lambda_0 (Y_2 - Y_1)$$

c. For zenith distances (refraction):

$$\begin{aligned} \bar{f}_1 &= f_1 + k \cdot P_1 / R_1 \\ \bar{f}_2 &= f_2 + k \cdot Q_1 / R_1 \\ \bar{f}_3 &= f_3 \\ \bar{f}_4 &= f_4 - k \cdot P_1 / R_1 \\ \bar{f}_5 &= f_5 - k \cdot Q_1 / R_1 \\ \bar{f}_6 &= f_6 \\ \bar{f}_7 &= -R_1 \end{aligned} \tag{3.76}$$

d. For spatial distances (scale):

$$g_7 = -S \tag{3.77}$$

Variance Models

In the publication Standards and Specifications for Geodetic Control Networks (FGCC 1984), a four-step process is described which leads to the accuracy classification for a project submitted to the NGS (Milbert 1985b). The first step details examining all aspects pertaining to the incoming surveys (e.g. measurements, field records, sketches, etc.) for compliance with the measurement system specifications. Next, a least squares adjustment performed on the survey aids in the detection of blunders and verifies correct weighting of each observation. The third step is also part of the least squares adjustment. This step computes the length relative accuracies by error propagation in order to determine the provisional accuracy. The final step is computing a variance factor by the Iterated Almost Unbiased Estimator (IAUE) method (Lucas 1985). Variance factors serve to detect some systematic errors.

Once the variance factor is computed, a variance factor ratio test is performed. The variance factor ratio is the variance factor of the new survey combined with the network data, divided by the variance factor of the survey alone. This test helps detect systematic errors, possibly in the control network, possibly in the incoming survey, or possibly in both. This final step helps determine that a survey is accurate and not merely precise (Milbert 1983). However, the use of variance factors to detect systematic error is not foolproof. For example, a global scale error is not detectable in a minimally constrained survey adjustment (FGCC 1984). A survey which was connected to the network at only one or no existing control points would not be able to detect systematic error between the survey and the network.

The variance factor for the new survey is computed by the IAUE method. In this method, the observations are grouped into k groups, to each of which is associated a variance factor, f_i

$$\Sigma_{L_b} = f_1 \Sigma_1^{\circ} + f_2 \Sigma_2^{\circ} + \ldots + f_k^{\circ} \Sigma_k^{\circ}$$

where Σ_{L_b} is a symmetric variance-covariance matrix which contains information on observation precision and correlation. From the above equation we can now estimate k different local variance factors,

$$\Sigma_{L_b} = \begin{bmatrix} f_1 \Sigma_1^{\circ} & 0 & \ldots & 0 \\ 0 & f_2 \Sigma_2^{\circ} & \ldots & 0 \\ \vdots & \vdots & & \\ 0 & 0 & \ldots & f_k \Sigma_k^{\circ} \end{bmatrix} .$$

The initial estimate of the k-th variance factor in the above model can be written as

$$f_k = \frac{(V^t \Sigma_{L_b}^{-1} V)_k}{tr\ (Q_k)}$$

where Milbert (1985) computes Q (the central redundancy matrix) as

$$Q = I - W = I - R^{-t} A N^{-1} A^t R^{-1} .$$

Table 3.8 shows the equations for the various error analysis quantities which can be computed in ADJUST. The software allows the option of computing either a priori or a posteriori statistics. The a posteriori variances are scaled by the sample variance of unit weight.

$$\hat{\sigma}_o^2 = \frac{V^t \Sigma_{L_b}^{-1} V}{n - u}$$

where
n is number of observations
u is number of unknowns.

If more detail is required, Milbert (1985a) and Baarda (1968) may be consulted.

Table 3.8.--General error analysis equations

a. Quasi-normalized residuals (v')

$$v' = v/\sigma_{L_b}$$

where v is the residual and σ_{L_b} standard deviation of the measured observation.

b. Standardized (normalized) residuals ($\bar{v}$)

$$\bar{v} = v/\sigma_v$$

where σ_v is the standard deviation of the residual.

c. Redundancy number (q)

$$q = 1 - \sigma^2_{L_a}/\sigma^2_{L_b} = \sigma^2_v/\sigma^2_{L_b}$$

where σ_{L_a} is the standard deviation of the computed observation.

d. Marginally Detectable Errors (MDE)

$$MDE = (\lambda\ \sigma^2_{L_b}/q)^{1/2}$$

where λ was preselected as 9.

4. PROGRAM IMPLEMENTATION

The first phase of processing inside ADJUST is to determine the options required in the run. This is done by processing the adjustment file in subroutine AFIL. This processing also determines the number of auxiliary parameters to be allocated in memory.

Memory Maps

In program ADJUST, a large array, A, is assigned. ADJUST then manages this space to fit the particular adjustment problem.

Figure 4.1 displays the memory map for ADJUST. The user may wish to refer to SUBROUTINE ALOCAT while reading the map. Once the number of stations, NSTA, and the number of parameters, NUNK, have been determined, the storage can be allocated. Each of the regions on the main map are further subdivided according to figures 4.2 through 4.5.

Figure 4.2 shows the arrangement in the Data Storage Block. The function GETPRM is used to compute an index into the auxiliary parameter sub-block. Function GETZ computes an index into the direction orientation parameter sub-block. The function GETSSN can be used to compute an index into the remainder of the Data Storage Block.

Figure 4.3 gives the arrangement of the Googe numbers (Schwarz 1978: 29-32). This arrangement is also the mapping of the order of the parameters. As with the Data Storage block, functions GETPRM, GETZ and GETSSN can be used to compute indices. Since this arrangement is also the parameter order, function INVIUN can be used to determine parameter types when given an index to a Googe numbers.

Figure 4.4 displays the memory map for the position shifts. The shifts are in the respective local geodetic horizon systems (x, y, z). This region can be indexed by converting a Blue Book Station Serial Number (SSN) into an internal station number (ISN) using GETSSN. The ISN is then used as input for IUNSHF.

Figure 4.5 displays the map for the work area used for decorrelation of the GPS vectors. This area is allocated for a maximum of five correlated GPS vectors (MAXVEC = 5 in subroutine ALOCAT). The work area is then re-partitioned for each vector set (NVEC = 1 or NVEC =2). The upper triangular covariance matrix is stored in columns 1 through N1. The Cholesky factor is computed in place. The variances are stored in column 1, rows 2 through NR. Column N2 is a scratchpad column for decorrelation by subroutine COMRHS. The routines GETRHS and PUTRHS load and unload this scratchpad column, respectively.

The original and the decorrelated coefficients of the observation equations are stored in columns N2+1 through N3. Misclosures are stored in column N4, and the measured observations are stored in column N5.

When mode 3 processing is selected SUBROUTINE GPSSDV uses a slightly different map of the work area. The normalized residuals are stored in column N2. The standard deviation of the residuals are stored in column N4. Redundancy numbers are stored in column N3, destroying the observation equation coefficients.

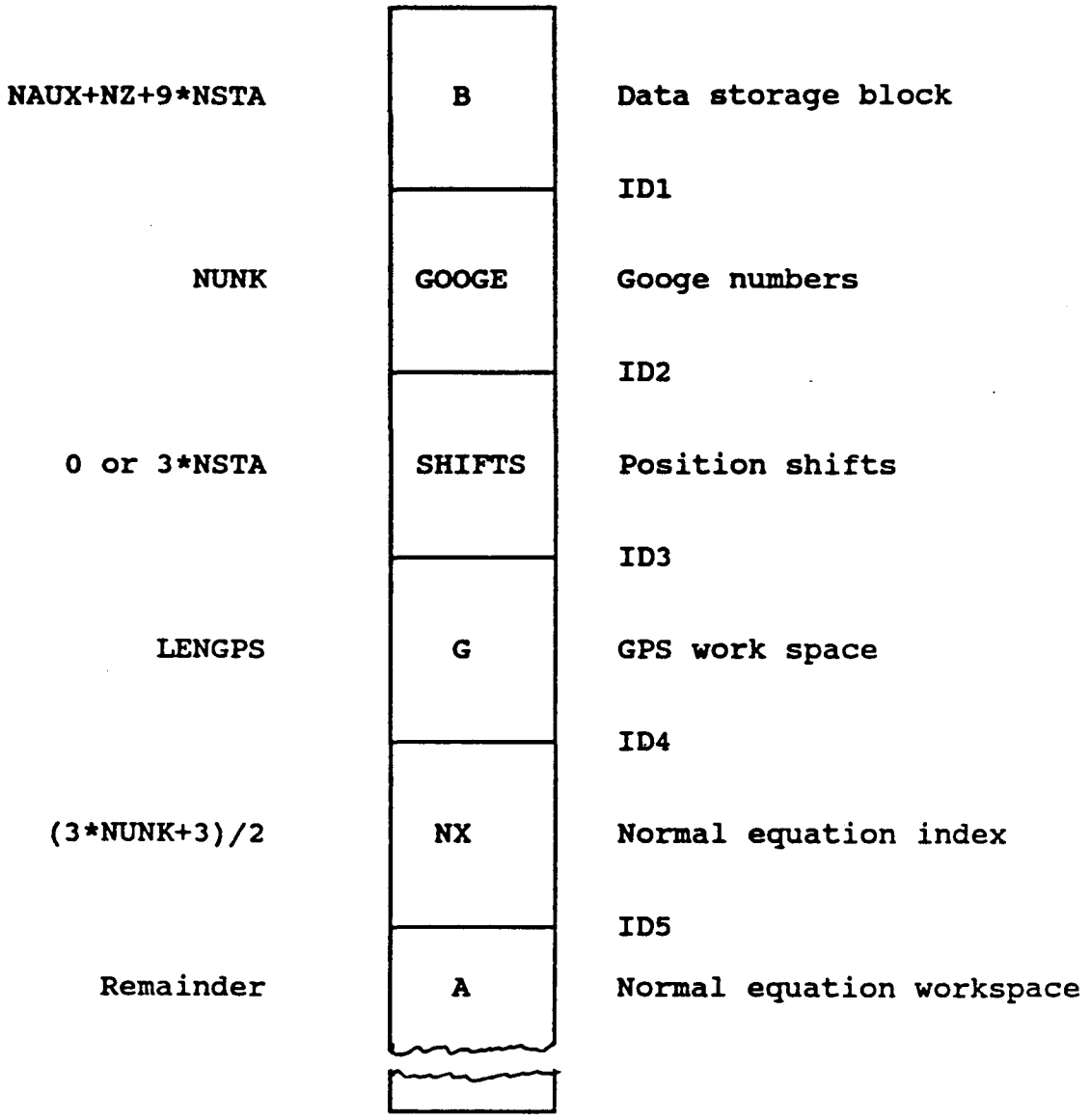

Figure 4.1.--Main memory map.

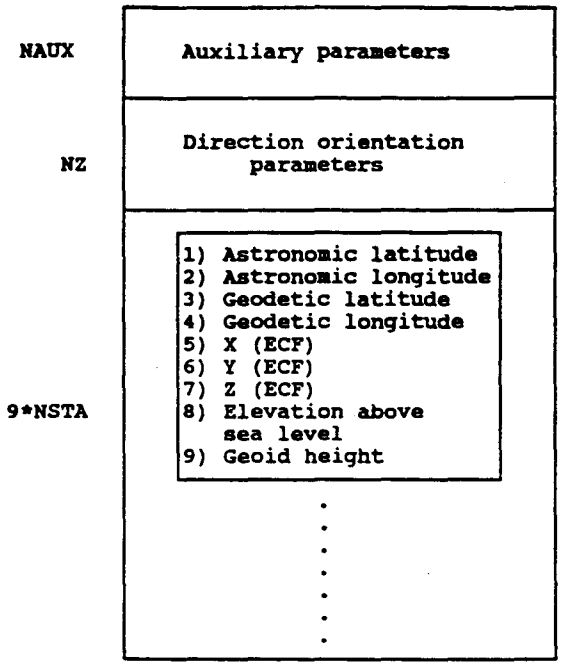

Figure 4.2.--Data storage block map.

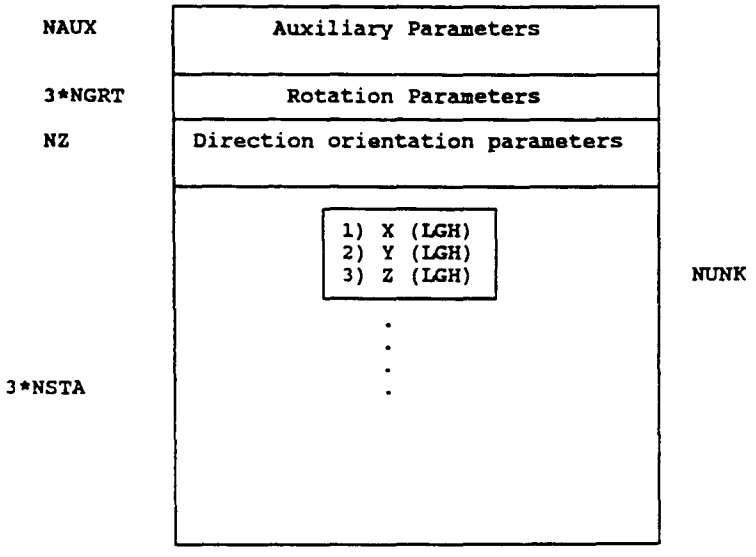

Figure 4.3.--Googe number map.

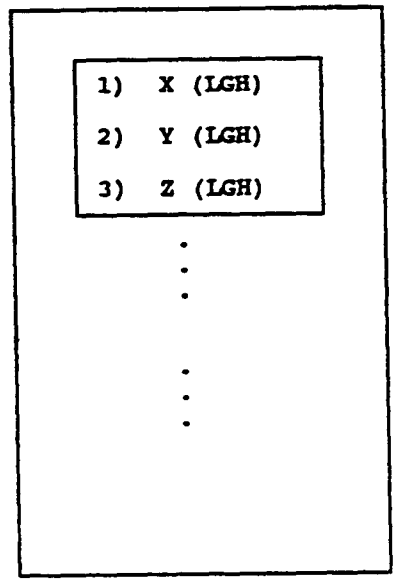

Figure 4.4.--Position shift memory map.

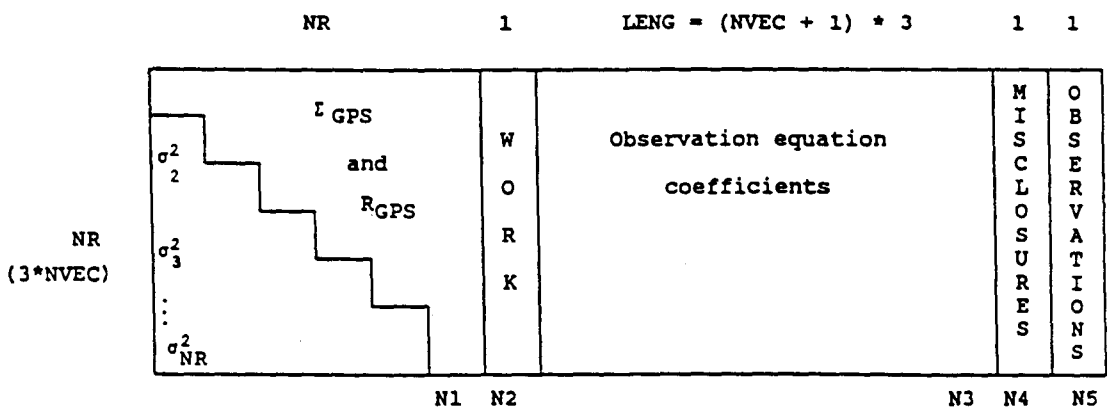

Figure 4.5.--GPS work area memory map.

In mode 0, which completes a simulation, marginally detectable errors (MDE) are stored in column N2.

The remainder of main memory is allocated to an index array, NX, and the normal equation array, A. Details on these arrays may be found in Milbert (1984).

Data Structures

The most heavily used special data structure in ADJUST is an array used to convert Blue Book Station Serial Numbers (SSN) into internal station numbers (ISN and JSN). This array is held in the common block named SSNTBL. The routines NEWSSN, GETSSN, PUTSSN, and LOCSSN insulate the user from direct (and potentially erroneous) manipulation of the index array.

Auxiliary parameters and variance factors are keyed by a time span and an observation type code. Separate named COMMON blocks hold the work arrays. As with the SSN table, these routines convert the keying information into an index. The direction orientations are keyed using a SSN and a list number. Other than the fact that a different key is used, the orientation utility routines function in the same fashion as the others.

Modifying the Memory Allocation

If it is necessary to increase or decrease the size of main memory, this is easily done in the main program. Modify the parameter named LENA. This will automatically cause LNWORK and LAWORK to be set to appropriate values.

If it is necessary to decrease the size of the SSN indexing down from 999, modify routines NEWSSN, GETSSN, PUTSSN, and LOCSSN. Note that the use of large legal SSN's will result in error messages if this modification is performed. Additional allocated space can be reduced by modifying the station indexing down from 999 in routines OBSSUM, NEWI, and CONTR.

If more than five sets of rotation parameters are needed, modify the COMMON block named /GRTTB2/ in routines PUTRTG and GETRTG.

If more than 30 auxiliary parameters are needed, modify routines NEWPRN, GETPRM, and PUTPRM.

If more than 30 variance factors are needed, modify routines NEWIUF GETIUF, PUTIUF, and FIXIUF.

If more than 700 intersection stations are observed, modify routines NEWFOT and RESID2.

If more than 3000 orientation unknowns (lists) are needed, modify routines NEWZ, GETZ, PUTZ, LOCZ, and INVZ.

If more than five GPS vectors (C records) are observed per session (B record), modify all instances of the parameter named NVEC. Use of a global search and replace edit function is recommended.

Implementation Restrictions

Since Fortran 77 requires predeclaration of the size of an array, certain lengths have been encoded into ADJUST. Note that the following numbers may vary based upon the particular computer version of ADJUST.

Main memory (LNWORK):	200,000 integer words
Maximum SSN:	999
Rotation parameters	5
Auxiliary parameters:	30
Variance factors:	30
Direction orientation unknowns:	3000 lists
Landmarks:	700
GPS vectors per session:	5

These restrictions will give rise to the anticipated error messages numbers: 8 through 20, 24, 27, 33, 39, and 63 in table 2.3. One may be able to circumvent these problems by increasing the storage allocation in ADJUST.

Machine Dependent Features

It is assumed that the INTEGER type declaration provides at least 32 bits to store an integer, and that the DOUBLE PRECISION declaration provides at least 60 bits to store a floating point number to sufficient accuracy. It is also assumed that the number of bits in two INTEGER words is equivalent to the bits in one DOUBLE PRECISION word.

Operating System Dependent Features

An "implicit" assumption of ADJUST is that a large amount of memory is available to store the A() array. If a virtual memory operating system is used, no problems should arise. Some operating systems require explicit declaration of the virtual arrays. Table 4.1 indicates the various "alias" names of the A() array.

Table 4.1.--Arrays stored in A() array

A
NX
B
GOOGE
SHIFTS
G

If a virtual memory operating system is not available, the user may wish to decrease the size of the A() matrix, as discussed earlier. If large systems need to be solved without virtual memory, ADJUST will need to be modified to use an "out of core" normal equation solver such as LASSO (or BIBB) (Dillinger 1982).

Language Extensions

No language extensions from the American National Standards Institute (ANSI) standard ANSI X3.9-1978 (FORTRAN 77) have been used.

Special Compiler Options

No special compiler options have been used in the development of ADJUST.

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