NETVAL

GPS Network Validation Software

IBM PC Version 1

Reference Manual

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INSTALLATION

READ THIS FIRST

The NETVAL distribution disks do not contain any disk operation system (DOS) and is therefore unable to "boot up" your computer system. You must use your own copy of DOS (e.g., PC-DOS or MS-DOS). The distribution disks are provided on double-sided disks and are usable only with double-sided disk drives. If you have an older single-sided drive, please ask for single-sided versions of the distribution disks.

Prior to using this software, make a copy of the distribution disks and store the originals in a safe place. **Do not use the distribution disks as working copies.** Refer to your DOS manual for instructions for copying disks.

Please read the text file READ.ME for the latest information not in this manual. To read the file use your favourite work processor or text editor or use the DOS TYPE command.

SYSTEM REQUIREMENTS

This software has been developed and tested on both IBM PC compatible and Macintosh computers. Current requirements for the IBM PC version of NETVAL, capable of handling 30 stations, are:

- at least 550 Kbytes of free random access memory (RAM);
- at least 1.4 Mbyte of free disk space for the executable programs;
- at least 450 Kbytes of free disk space for the source code;
- additional space for input and output data files and listings.

If you do not have enough RAM for the largest executable program (NETRAN), contact GRSL for a smaller version of this program. Although not specifically required with any of the programs, an 80x87 numeric coprocessor is highly recommended!

The strain plotting program PLTSTR currently runs only on IBM PC compatible computers and requires an EGA graphics adapter and colour monitor. In addition, output plots may be optionally printed on either an Epson compatible dot matrix printer connected to the LPT1 parallel port or on a Hewlett-Packard LaserJet II laser printer connected to the LPT2 parallel port.

Please call regarding custom versions for your own special equipment.

DISTRIBUTED FILES

The following files are distributed with the IBM PC version of NETVAL. These distribution files are self-extracting archive files. Each contains a number of files that have been compressed to take up less disk space for convenient distribution. Note that the source code files are only included with the source code version of NETVAL.

READ.ME	Text file containing the latest information not present in this manual; read this file first
NETVAL1.EXE	Self-extracting archive file containing the executable NETVAL programs (part 1)
NETVAL2.EXE	Self-extracting archive file containing the executable NETVAL programs (part 2)
EXAMPLES.EXE	Self-extracting archive file containing the examples for testing the NETVAL programs
SOURCE.EXE	Self-extracting archive file containing the source code to the NETVAL programs (included only with the source code version of NETVAL)

To extract the files within each archive, just enter the name of the archive file at the DOS prompt followed by the return or enter key. Each file will be automatically extracted to the current default directory. For example, to extract part 1 of the executable programs, enter the command

```
NETVAL1
```

If you wish to have the programs extracted and saved to a different directory, follow the name of the archive file with the full path of the directory. For example, to extract part 1 of the executable programs to the directory \NETVAL on drive C:, enter the command

```
NETVAL1 C:\NETVAL
```

The following files should be included within each of the above archive files:

NETVAL1.EXE Archive Files

NETREG.EXE	Network Confidence Regions
NETDIF.EXE	Network Coordinate Difference Analysis
NETRAN.EXE	Network Helmert (Datum) Transformation

NETVAL2.EXE Archive Files

NETSTR.EXE	Network Strain Analysis
PLTSTR.EXE	Plots Results from Program NETSTR (IBM PC only)

SOURCE.EXE Archive Files

NETREG.FOR	Network Confidence Regions
NETRAN.FOR	Network Helmert (Datum) Transformation
NETRAN.INC	Include file for NETRAN
NETDIF.FOR	Network Coordinate Difference Analysis
NETSTR.FOR	Network Strain Analysis
NETSTR1.INC	Include file for NETSTR
NETSTR2.INC	Include file for NETSTR
PLTSTR.FOR	Plots Results from Program NETSTR (IBM PC only); requires PLOT88™ graphics library

EXAMPLE.EXE Archive Files

BASE.IOB	Example GeoLab™ input observations file for base network
BASE.ADJ	Example TOOLKIT output adjusted coordintes file for base

network

BASE.DAT	Example NETVAL data file for base network
TEST1.DAT	Example NETVAL data file for 1st test network
TEST2.DAT	Example NETVAL data file for 2nd test network
BASE.REG	NETREG output listing for BASE.DAT base network
TEST1.DIF	NETDIF output listing for BASE/TEST1 comparison
TEST1.STR	NETSTR output listing for BASE/TEST1 comparison
TEST1.PLT	NETSTRN output plot file for BASE/TEST1 comparison (input to PLTSTR)
TEST2.TRN	NETRAN output listing for BASE/TEST2 comparison
TEST2X.TRN	NETRAN output listing for BASE/TEST2 comparison
TEST2X.DAT	NETRAN output transformed TEST2 data file
TEST2.STR	NETSTR output listing for BASE/TEST2 comparison
TEST2.PLT	NETSTRN output plot file for BASE/TEST2 comparison (input to PLTSTR)

INTRODUCTION

PURPOSE OF VALIDATION

The use of GPS positioning technology for routine geodetic surveying has raised the problem of how to assess the accuracy of such surveys. The studies conducted by Craymer et al. [1989b;c;d] have identified the problems associated with developing specifications for the rapidly changing GPS technology. Traditional specifications were rigid in design as a consequence of the limitations of traditional surveying instruments. Field procedures were well established and the accuracies of the instrumentation usually well known. This enabled agencies responsible for contracting out such surveys to devise specifications and procedures that were known, based on experience, to provide the required accuracies.

With the advent of GPS positioning, however, the traditional approach to specifications and procedures has ceased to be suitable. This is primarily due to the rapid advances in GPS technology, especially receiver design and processing software. For example, only a few years ago it was thought that at least an hour of GPS observations were required to get acceptable position differences. Today, with the use of stop-and-go (also known as semi-kinematic) procedures, users can obtain as good or even better accuracies with occupation times of only a few minutes. A more fundamental problem also exists with the estimation of reliable accuracies for GPS derived position differences and the future consequences of the possible implementation of “selective availability.”

As a result of these factors, Craymer et al. [1989b;c;d] have proposed to de-emphasize rigid specifications and procedures and to instead emphasize the idea of contractor qualification. That is, potential GPS contractors must successfully qualify for bidding on potential contracts by demonstrating their ability to perform satisfactory GPS surveys using their own equipment, procedures and software. Performing the qualification surveys on a network with well established positions will enable the contracting agency to evaluate the potential contractors results.

To aid the contracting agency in validating the results of such qualification surveys, we have developed this software package NETVAL, an acronym for Network Validation. It assembles a variety of techniques for evaluating the accuracy of 3-dimensional survey results by comparing them with well known (control) positions.

CONVENTIONAL APPROACH TO VALIDATION

The standard approach to classifying the results of geodetic surveys is to simply examine the 95% relative confidence ellipses. The results are deemed to meet a specified accuracy only if the major semi-axis of the ellipse are smaller than the allowed maximum for the accuracy level.

Application of this approach to GPS surveys is impaired by the lack of realistic accuracy information (i.e., covariance information) for the GPS derived positions. To the best of our knowledge, there is no commercially available GPS processing software that can provide realistic covariance matrices from which reliable confidence regions can be determined. Without such information, confidence regions become meaningless as do all statistical tests.

Although relative information in formal GPS covariance matrices seems to be reliable, research has indicated that a scale problem exists. Consequently some GPS software packages and contractors scale their individual baseline covariance matrices to predetermined accuracies using (hidden) built-in factors that often depend on baseline length.. Using these scaled covariance matrices in a 3-dimensional network adjustment of the baselines gives confidence regions that are guaranteed to meet the predetermined accuracy. GPS software that directly combine the GPS observations into a network solution makes the individual scaling of baselines more difficult. Nevertheless is it still possible to simply scale the entire covariance matrix by a constant factor. Clearly this accuracy information is almost useless for validating a potential contractor's results.

NETVAL APPROACH TO VALIDATION

To overcome the problems with unreliable statistical information (i.e., covariance matrix), we have developed the NETVAL suite of programs for validating 3-dimensional network surveys. The approach used by our software is to evaluate both the internal and external accuracy of the network of new GPS determined points.

The internal accuracy of the results to be evaluated is assessed in the usual manner using absolute and relative confidence regions determined from the network covariance matrix. All of the major semi-axes for both 2-d (horizontal) and 3-d 95% relative confidence regions must meet the required accuracy standards with respect to baseline length (see below).

The external accuracy is assessed by comparing a potential contractor's results from a test survey of a qualification network with “known” control values. The test network can be analysed in terms of statistical compatibility (statistical testing), datum differences and local systematic distortions (strain). The more control points that are included in the network, the more reliable are the results of the tests. To facilitate the interpretation of the results of these tests it is important that the qualification results come from a minimally constrained adjustment (e.g., one point held fixed or generalized inverse used).

In general, the validation procedure would involve the following steps:

(i) Assessment of internal accuracy. Relative confidence regions are determined and checked if they meet the required order of accuracy. This will ensure that the covariance matrix has not been purposely scaled up to ensure that it passes the statistical compatibility tests with the control network.

(ii) Assessment of external accuracy in terms of the statistical compatibility of the test and control positions of networks points. The compatibility is assess using statistical tests of differences in the positions from the two networks. The coordinate differences should not be statistically different from zero providing the relative confidence regions meet the appropriate accuracy standard (i.e., acceptable internal accuracy). The magnitude of the coordinate differences should also be less than that allowed for the order of accuracy. If the covariance matrix from the qualification survey is overly optimistic (too small so they meet the required relative accuracy standard), the coordinate differences may be incorrectly determined as (statistically) significantly different from zero. It is conceivable that contractors may optimize the scale of the covariance matrix so that their results pass both tests of the confidence regions and tests of compatibility with the control results. If so, the contractor must report the scale factor and continue to use this for all surveys to ensure that they at least provide consistent results.

(iii) Assessment of external accuracy in terms of network-wide distortions with respect to the control network. Any possible datum differences between the qualification and control results are determined using a weighted Helmert transformation. If a minimally constrained adjustment has been performed with the correct coordinates for the fixed point, there should be no statistically significant datum differences. The existence of any datum differences could be caused by a number of factors, including the use of an over-constrained adjustment, incorrect coordinates for the fixed station or incorrect GPS ephemerides. If significant datum differences exist and are justifiable (e.g., the use of NAD27 instead of NAD83), the results may be transformed to the control network datum for further testing.

(iv) Assessment of external accuracy analysis in terms of local systematic distortions. Local systematic distortions at each station in the test network with respect to the control network are determined from a strain analyses of the coordinate differences between the two networks. The strain analysis is performed using the technique described in Craymer et al. [1989a]. The strain parameters depict the coordinate differences as local distortions in terms of differential rotation (twisting at a point) and strain ellipses (scale changes at a point). Because the units of the stain parameters are in ppm (radians are equivalent to ppm), the strain parameters should all be less than the required relative accuracy.

Accuracy Specifications

Canadian specifications for 95% horizontal relative confidence ellipses are given by [Surveys and Mapping Branch, 1978]

$$r = c\,(d + 0.2)\ ,$$

where

- r is the maximum allowable size of the major semi-axis in cm,
- d is the distance between the two points in km,
- c is a factor for the order of survey (c=2 for 1st-order, c=5 for 2nd order, c=12 for 3rd order).

This specification is defined only for 2-d (horizontal) surveys. The specification can be extended to 1-d and 3-d by re-scaling this maximum limit using the appropriate factor for 1-d and 3-d confidence levels (i.e., the square root of the value from the Chi-square tables for the desired confidence level and degrees of freedom equals to the dimension of the confidence region). Each of the confidence regions are be based on the same standard error(unscaled).

The maximum limit for the standard confidence ellipse is found by dividing the 2-d 95% limit by its scale factor (2.447). 1-d and 3-d confidence regions are then obtained by multiplying by the appropriate scale factor. For the 95% confidence level, the scale factors and resulting maximum allowable limits for the relative confidence regions are:

Region	Scale Factor	Maximum (95% level) Allowable Size (cm)
Standard	1.00	c (d + 0.2) / 2.447
1-d	1.96	c (d + 0.2) (1.96/2.447)
2-d	2.447	c (d + 0.2)
3-d	2.795	c (d + 0.2) (2.795/2.447)

OVERVIEW OF NETVAL PROGRAM SUITE

The NETVAL software consists of a suite of programs that perform the above analyses. All of the programs are interactive in operation, each prompting the user for all required input. The following summarizes each of the programs functions.

NETDAT Network Data File. Creates a network data file in the format required for the NETVAL analysis programs from GeoLab™ and GHOST data files.

NETREG Network Confidence Regions. Performs an internal accuracy analysis of a single network by computing the relative confidence regions at a specified confidence level.

NETRAN Network Helmert (Datum) Transformation. Performs an external accuracy analysis by computing any network-wide datum differences between the test and control networks.

NETDIF Network Coordinate Difference Analysis. Performs an external accuracy analysis by computing coordinate differences, checking whether the magnitude of the differences exceed the allowed accuracy limits and testing the statistical compatibility of the test and control networks.

NETSTR Network Strain Analysis. Performs an external accuracy analysis by computing strain parameters at each point from the coordinate differences between the test and control networks. Also creates an output data file for plotting the strain parameters using PLTSTR.

PLTSTR Plots Strain Parameters. Plots strain parameters at each point in the network using the output data file from NETSTR.

With the exception of NETDAT and NETREG, all of these programs require the same input data files for the test and control networks. NETREG requires only the data file for the test network. NETRAN also optionally generates a data file of the test network transformed to the control network datum.

EXAMPLES

As a training aid for the use of the software and to verify that the programs are operating properly, input data and output listing files are provided as examples. All of these files are based on an actual GPS survey of Alberta Forestry, Lands and Wildlife Land Information Services Division's GPS qualification network by the Canada Centre for Surveying. The BASE.DAT file contains the results of the GPS survey. It has been generated by the NETDAT program from the GeoLab™ input file BASE.IOB and the TOOLKIT output adjusted coordinates file BASE.ADJ. The file TEST1.DAT has been generated by the NETDAT program from the GeoLab™ input file TEST1.IOB and the TOOLKIT output adjusted coordinates file TEST1.ADJ. The files TEST1.DAT and TEST2.DAT are simulated test networks that have been generated from the BASE.DAT file using random errors and a Helmert transformation (the latter for testing the NETRAN program).

The following example data files are included:

BASE.IOB	GeoLab™ input obsrvations file for base nework (actual CCS GPS survey);
BASE.ADJ	GeoLab™ TOOLKIT output file of adjusted 3-d coordinates for the base network;
BASE.DAT	NETVAL data file for the base network (created by NETDAT from BASE.IOB and BASE.ADJ);
TEST1.DAT	NETVAL data file for the 1st test network (created by perturbing the coordinates in the BASE.DAT file by random errors with zero mean and 0.03 m standard deviation);
TEST2.DAT	NETVAL data file for the 2nd test network (created by transforming the coordinates in the TEST1.DAT file by a 0.1 m translation along the local geodetic x-axis, a 10" rotation about the local geodetic z-axis (i.e., rotation in azimuth), a 2 ppm scale change and perturbed by random errors with zero mean and 0.03 m standard deviation).

SUGGESTED FILE NAMING CONVENTION

To facilitate the management of the input and output files generated by the NETVAL programs, the following file naming scheme is recommended, ABC is a code denoting the contractor.

Input to programs	ABC.DAT	Contractor's (test) network data file
NETREG output	ABC.REG	Listing of results
NETRAN output	ABC.TRN ABCX.DAT	Listing of results Transformed data file
NETDIF output	ABC.DIF	Listing of results
NETSTR output	ABC.STR ABC.PLT	Listing of results Plot data file
PLSTR input	ABC.PLT	Plot data file from NETSTR

NETDAT
NETWORK DATA FILES

INTRODUCTION

All NETVAL analysis programs (NETREG, NETDIF, NETRAN, NETSTR) require the same input data files. The results should come from a minimally constrained adjustment (e.g., only one point is held fixed or generalized inverse used). The format for the data files is described below. The ordering of the information must be strictly followed and the items on each line must be separated by blanks, commas or tabs. For an example refer to the data file BASE.DAT in the Appendix.

Line Order	Contents	Data Type
1	Identification String (max 80 characters)	character
2	Number of stations	integer
	Station number of fixed station (max 10 characters)	character
3	Station number and coordinates. Each station begins on a new line and includes the following:	
	Station number (max 10 characters)	character
	Latitude: degrees	integer
	minutes	integer
	seconds	real
	Longitude: degrees	integer
	minutes	integer
	seconds	real
	Geodetic height (metres)	real
	Orthometric height (metres)	real
4	Covariance matrix scale factor	real
5	Formal (unscaled) covariance matrix elements (in local geodetic system and metres^2) obtained from the adjustment software. Only the lower trangular portion of the matrix should be entered. Each row begins on a new line using a maximum of 80 columns per line.	real
6	Number of observations (ties)	integer
7	Observation ties. Each new observation begins on a new line and includes the following:	
	Observation number	integer
	From station number (max 10 characters)	character
	To tation number (max 10 characters)	character

The program NETDAT may be used to create network data files from files input to and created by the 3-d adjustment program GeoLab™. The required input files to NEDAT are:

(i) the input file to the GeoLab™ program containing the baseline observations and

(ii) the data file created by the GeoLab™ TOOLKIT utility program containing the adjusted station coordinates and their covariance matrix (treated as position observations for input to another adjustment).

NETDAT will then create a network data file following the above format for input to the NETVAL analysis programs.

NETDAT OPERATION

To run NETDAT enter the following command at the DOS prompt:

```
NETDAT
```

As soon as the program loads into memory, the program identification will be displayed and the user will be sequentially prompted to enter the names of the GeoLab™ files, the NETVAL data file to be created, the number of the fixed station and an identification header for the NETVAL data file.

A typical session is illustrated in Figure 1. Each of the prompts will be discussed separately. In all cases, execution of the program may be terminated at any time by pressing the Ctrl and C (or Break) keys simultaneously.

```
Enter GeoLab(tm) input observations data file >
```

Enter the name of the input data file for the GeoLab™ (or GHOST) adjustment program containing the 3-d baseline observations. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

```
Enter GeoLab(tm) TOOLKIT output adjusted coord. file >
```

Enter the name of the GHOST data file (for input to the GHOST adjustment program), created by a GeoLab™ utility program, containing the adjusted 3-d positions of all stations and their covariance matrix. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

```
Enter NETVAL data file to be created >
```

Enter the name to use for the output network data file in NETVAL format. If the file already exists, the program will display the following prompt .

```
---------------------------------------------------------
 NETDAT:  Creates NETVAL data file from GeoLab(tm) files
          Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
---------------------------------------------------------

Enter GeoLab(tm) input observations data file > base.iob

Enter GeoLab(tm) TOOLKIT output adjusted coord. file > base.adj

Enter NETVAL data file to be created > base.dat

***** File already exists.  Overwrite it? (Y,N) > y

Enter fixed station number > 77X251

Enter header id for NETVAL data file :
CCS 1990 GPS Validation Survey

Reading adjusted positions...
Reading covariance matrix of adjusted positions...
Reading baseline observations...
Writing data to output file...
NETDAT finished.
```

Figure 1: Example NETDAT session (underscores indicate user input).

`***** File already exists.  Overwrite it? (Y,N) >`

Enter `Y` if you wish to overwrite the existing file or `N` if not. If not overwriting the existing file, the program will prompt again for the output listing file.

`Enter fixed station number >`

Enter the station number (max. 10 characters) that was fixed in the minimally constrained adjustment.

`Enter header id for NETVAL data file >`

Enter a maximum of 80 characters to use as the identification header for the NETVAL network data file (first line in the file).

After the required data are correctly entered, the program reads the adjusted positions and their covariance matrix from the GeoLab™ TOOLKIT output file and the baseline observations from the GeoLab™ input file and writes the information to a newly created network data file for use by the NETVAL analysis programs.

EXAMPLE

The input and output data files for the example run of NETDAT in Figure 1 are given in the Appendix (see BASE.IOB, BASE.ADJ, BASE.DAT).

NETREG
NETWORK CONFIDENCE REGIONS

METHODOLOGY

Confidence regions can be used to assess the internal accuracy of a network in the usual way. Absolute station confidence regions (i.e., 3-d ellipsoids) describe the accuracy of a point with respect to the fixed point in a minimally constrained adjustment. Relative station confidence regions describe the accuracy of point with respect to another arbitrary point in the network. Absolute confidence regions are really only relative confidence regions of points with respect to the fixed point. Absolute and relative station confidence regions are computed for each point using only the 3x3 part of the full network covariance matrix corresponding to the point. Relative confidence regions are computed for all possible station pairs. The covariance matrix for the relative confidence regions are determined from the sum of the covariance matrices for the test and control networks. Any covariance between the networks is ignored.

NETREG computes confidence regions from the eigenvalues and eigenvectors which are determined using the diagonalization method of Jacobi. The length of the major semi-axis is the square root of the largest eigenvalue, the medium semi-axis is the square root of the next largest eigenvalue and the minor semi-axis is the square root of the smallest eigenvalue. The orientation of each axis is defined by its corresponding eigenvector. If (x,y,z) are the components of an eigenvector in the local geodetic coordinate system, its orientation is given by the azimuth (a) and inclination (i):

$$a = \arctan\left(\frac{y}{x}\right),$$

$$i = \arctan\left(\frac{z}{\sqrt{x^2+y^2}}\right).$$

In addition to providing 3-d confidence ellipsoids, NETREG also determines the projections of the ellipsoid onto the horizontal plane and vertical axis at each station. The horizontal projection is simply the confidence ellipse corresponding to the covariance matrix for only the x,y coordinate components. The vertical projection is simply the standard deviation of the z component.

Note that the confidence regions are scaled differently depending on the dimension of the region. That is, the scale factor for the 3-d confidence region is that for the confidence ellipsoid (e.g., 2.795 for 95%). The scale factor for the 2-d horizontal projection is that for the confidence ellipse (e.g., 2.447 for 95%). The scale factor for the 1-d vertical projection is that for the confidence interval (e.g., 1.96 for 95%).

NETREG OPERATION

To run NETREG enter the following command at the DOS prompt:

```
NETREG
```


As soon as the program loads into memory, the program identification will be displayed and the user will be sequentially prompted to enter the name of the input data file for the (test) network to be analysed, the name output listing file and the confidence level to use for the confidence regions.

A typical session is illustrated in Figure 2. Each of the prompts will be discussed separately. In all cases, execution of the program may be terminated at any time by pressing the Ctrl and C (or Break) keys simultaneously. Note the input errors in Figure 2.

```
-------------------------------------------------------
 NETREG:  Network Confidence Regions
          Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

Enter input data file for network > bas.dat

***** Error: File does not exist.

Enter input data file for network > base.dat

Enter output listing file > base.reg

***** File already exists.  Overwrite it? (Y,N) > y

Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) > 83

Enter speficied order of accuracy (1=1st, 2=2nd, 3=3rd) > 1

Enter confidence level for statistical tests (%) > 95

Reading input data file...
Computing absolute 3D confidence regions...
Computing absolute 2D and 1D confidence regions...
Computing relative 3D confidence regions...
Computing relative 2D and 1D confidence regions...
NETREG finished.
```

Figure 2: Example NETREG session (underscores indicate user input).

`Enter input data file for network >`

Enter the name of the data file for the (test) network to be analysed. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

`Enter output listing file >`

Enter the name to use for the output listing file containing the results. If the file already exists, the program will display the following prompt .

`***** File already exists.  Overwrite it? (Y,N) >`

Enter `Y` if you wish to overwrite the existing file or `N` if not. If not overwriting the existing file, the program will prompt again for the output listing file.

```
Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) >
```

Select the type of reference ellipsoid used for the network data files by entering either `27` for NAD27, `83` for NAD83 or `0` to enter your own ellipsoid definition. If defining your own ellipsoid, the program will display the following prompts

```
Enter major semi-axis (m) >
Enter inverse flattening >
```

Enter the major semi-axis (in metres) and the inverse of the ellipsoid flattening (e.g., 294.9786982 for NAD27) to each of these prompts, respectively, in order to define the size and shape of the ellipsoid.

```
Enter specified order of accuracy (1=1st, 2=2nd, 3=3rd) >
```

Enter the desired order of accuracy to use in determining the maximum allowable size of the 95% confidence regions. The specified maximum errors for each of these orders are derived from the 2-d 95% confidence ellipses defined by the Surveys and Mapping Branch [1978] (refer to the Methodology section).

```
Enter confidence level for statistical tests (%) >
```

Enter the desired confidence level in percent (i.e., `95 for the 95% confidence level`).

After the required data are correctly entered, the program computes all absolute and relative confidence regions. The output listing file may then be printed or displayed.

INTERPRETATION OF RESULTS

The output provided by NETREG includes the following information (see example file CCS.REG in the Appendix).

- Input network data file and its identifying character string (1st line in the data file).
- Confidence level (%) for confidence regions.
- 1-d scale factor for scaling the projection of the error ellipsoid on to the vertical axis (i.e., scale factor for confidence interval).
- 2-d scale factor for scaling the projection of the error ellipsoid on to the horizontal plane (i.e., scale factor for confidence ellipse).
- 3-d scale factor for scaling the standard error ellipsoid to the confidence region.
- Specified order of accuracy for determining the maximum allowable errors at the 95% confidence level.
- Confidence level for statistical tests (percent).

- Absolute confidence regions for each station, including the following information for each:
    - Station name;
    - 3-d distance (m) from the fixed station;
    - 3-d specifications for maximum allowable size (m) of the ellipsoid axes;
    - Length (m) of each of the 3-d confidence ellipsoid axes;
    - Azimuth (deg) of each of the 3-d confidence ellipsoid axes;
    - Inclination (deg) of each of the 3-d confidence ellipsoid axes;
    - Flag indicating whether the 3-d ellipsoid meets (passes) or exceeds (fails) the 3-d specifications;
    - 2-d distance (m) from the fixed station;
    - 2-d specifications for maximum allowable size (m) of the ellipse axes;
    - Length (m) of each of the 2-d confidence ellipse axes;
    - Azimuth (deg) of each of the 2-d confidence ellipse axes;
    - Length of the 1-d (vertical) confidence interval;
    - Flag indicating whether the 2-d ellipse meets (passes) or exceeds (fails) the 2-d specifications;
- Relative confidence regions for all station pairs, including the same information as for the absolute confidence regions.

The internal accuracy of the network can be inferred from the relative error ellipsoids by examining the largest axis length for each station pair. The largest axis must be less than the maximum allowed for the specified order of accuracy. The results of these tests are indicated by the pass/fail flags.

EXAMPLE

The input data file and output listing of the example run of NETREG in Figure 2 are given in the Appendix (see BASE.REG). Note the input errors. This example analyses the internal accuracy of the actual CCS 1990 GPS survey to be used as the control (base) network for the other analyses.

In order to determine if a network meets the required accuracy standard it is necessary to ensure that the size of all relative confidence regions is less than the 2-d and 3-d Specs given in the output listing BASE.DIF (see Appendix). It is found that all relative confidence regions are within the allowable maximum.

NETDIF
NETWORK COORDINATE DIFFERENCE ANALYSIS

METHODOLOGY

The external accuracy of the test network can be assessed by examining its statistical compatibility with “known” coordinates established by higher-order methods. The Chi-square test can be used for this purpose. Letting $\mathbf{\Delta x}$ denote a vector of coordinate differences, the confidence region is given by

$$\mathbf{\Delta x}^T \mathbf{C}_{\mathbf{\Delta x}}^{-1} \mathbf{\Delta x} \le \xi_{\chi^2_{u,1-\alpha}} ,$$

where $\xi_{\chi^2_{u,1-\alpha}}$ is the value from the Chi-square tables for u degrees of freedom (number of coordinate components compared) and the $1-\alpha$ confidence level. If $\mathbf{\Delta x}^T\mathbf{C}_{\mathbf{\Delta x}}^{-1}\mathbf{\Delta x}$ is less then this limit, then the hypothesis that the coordinate differences are statistically equivalent to zero is accepted. If larger than the limit, the hypothesis is rejected and the station may be considered to be statistically incompatible with the control network.

Various combinations of the coordinates may be tested together by defining $\mathbf{\Delta x}$ and $\mathbf{C}_{\mathbf{\Delta x}}$ in different ways. The following tests are used in NETDIF:

(1) $\mathbf{\Delta x}$ containing only the 3-d coordinate differences (x,y,z) at a single station (u=3),

(2) $\mathbf{\Delta x}$ containing only the x (north) coordinate differences (u=number of stations),

(3) $\mathbf{\Delta x}$ containing only the y (east) coordinate differences (u=number of stations),

(4) $\mathbf{\Delta x}$ containing only the z (height) coordinate differences (u=number of stations),

(5) $\mathbf{\Delta x}$ containing only the differences in the 2-d horizontal (x,y) components (u=2 times the number of stations),

(6) $\mathbf{\Delta x}$ containing all the 3-d (x,y,z) coordinate differences (u=3 times the number of stations).

Note the number of the degrees of freedom (u) for each test. Note also that the first test of individual stations is performed in NETRAN when assessing the residual coordinate differences after transformation.

The above Chi-square tests of parts of the total network coordinate vector (tests 1 to 5) are performed out-of-context of the other parameters. That is, they neglect the presence of the other parameters. These tests may also be performed in the context of the other complement tests so that the simultaneous probability of these tests is equal to the desired confidence level (see Vaníček and Krakiwsky [1986]).

The so-called in-context tests are performed in exactly the same manner as the out-of-context ones except that the significance level α/m is used in place of α, where m is the total number of parameters divided by the number of parameters used in the test. For example, test 1 requires using α/p in place of α (p is the number of points in the network), tests 2, 3, and 4 use $\alpha/3$ and test 5 uses $2\alpha/3$. Test 6 uses all parameters and thus the out-of-context and in-context tests are the same for this case. This is summarized in the following table:

In-Context Significance Levels for Simultaneous Confidence Level α

Test	Significance Level
1	α / p
2,3,4	α / 3
5	2 α / 3
6	α

A number of other quantities are also supplied by NETDIF. These include the following:

- Distance from fixed point and maximum allowable error for the specified order of accuracy,
- Mean and standard deviation of all the (x,y,z) coordinate differences as well as separately for the x, y, z and horizontal (x,y) coordinate differences,
- Maximum coordinate differences in x, y, z, horizontal (x,y) and 3 d (x,y,z) and the corresponding station name.

NETDIF OPERATION

To run the NETDIF program enter the following command at the DOS prompt:

```
NETDIF
```

As soon as the program loads into memory, the program identification will be displayed and the user will be sequentially prompted to enter the name of the input data file for the control (base) network, the name of the input data file for the (test) network to be analysed, the name of the output listing file and the type of reference ellipsoid to use.

A typical session is illustrated in Figure 3. Each of the prompts will be discussed separately. In all cases, execution of the program may be terminated at any time by pressing the Ctrl and C (or Break) keys simultaneously.

```
Enter input data file for 1st (base) network >
```


Enter the name of the data file for the control (base) network. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

```
Enter input data file for 2nd (test) network >
```

Enter the name of the data file for the (test) network to be analysed. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

```
Enter output listing file >
```

Enter the name to use for the output listing file containing the results. If the file already exists, the program will display the following prompt .

```
***** File already exists.  Overwrite it? (Y,N) >
```

Enter `Y` if you wish to overwrite the existing file or `N` if not. If not overwriting the existing file, the program will prompt again for the output listing file.

```
-------------------------------------------------------
 NETDIF:  Network Coordinate Difference Analysis
          Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

Enter input data file for 1st (base) network > base.dat

Enter input data file for 2nd (test) network > test1.dat

Enter output listing file > test1.dif

Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) > 83

Enter specified order of accuracy (1=1st, 2=2nd, 3=3rd) > 1

Enter confidence level for statistical tests (%) > 95

Reading data from 1st network...
Reading data from 2nd network...
Finding common stations and sorting data...
Computing coordinate discrepancies...
Comparing discrepancies with specifications...
Performing station Chi-square tests...
Performing network Chi-square tests...
NETDIF finished.
```

Figure 3: Example NETDIF session (underscores indicate user input).

```
Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) >
```

Select the type of reference ellipsoid used for the network data files by entering either `27` for NAD27, `83` for NAD83 or `0` to enter your own ellipsoid definition. If defining your own ellipsoid, the program will display the following prompts

```
Enter major semi-axis (m) >
Enter inverse flattening >
```

Enter the major semi-axis (in metres) and the inverse of the ellipsoid flattening (e.g., 294.9786982 for NAD27) to each of these prompts, respectively, in order to define the size and shape of the ellipsoid.

```
Enter specified order of accuracy (1=1st, 2=2nd, 3=3rd) >
```

Enter the desired order of accuracy to use in determining the maximum allowable size of the 95% confidence regions. The specified maximum errors for each of these orders are based on the 2-d 95% confidence ellipse as defined by Surveys and Mapping Branch [1978]. See the NETREG Methodology section for 1-d and 3-d limits.

```
Enter confidence level for statistical tests (%) >
```

Enter the desired confidence levelin percent (i.e., `95 for the 95% confidence level`).

After entering all of the required data, the program performs all of the statistical tests described above, both on a station-by-station basis as well as on the entire network as a whole. The results are then written to the output listing file for later viewing or printing.

INTERPRETATION OF RESULTS

The output provided by NETDIF includes the following information (see example file CCS1.DIF in the Appendix).

- Name of the 1st (base or control) network data file and its identifying character string (1st line in the data file).
- Name of the 2nd (test) network data file and its identifying character string (1st line in the data file).
- Major semi-axis (m) and inverse of flattening for the selected reference ellipsoid.
- Specified order of accuracy for determining the maximum allowable errors at the 95% confidence level.
- Confidence level (percent) for the statistical tests.
- Station coordinates for both networks, including station number, latitude (deg, min, sec), longitude (deg, min, sec) and ellipoidal height (m) of each point.
- Coordinate discrepancies (test network minus base network), including the following information for each station:

  - Station number;
  - Coordinate discrepancies (dx,dy,dz in m) in local geodetic x (north), y (east) and z (vertical);
  - Standard deviations (m) of dx, dy, dz;
  - Length (m) of 2-d vector of coordinate discrepancies;
  - Length (m) of 3-d vector of coordinate discrepancies.

- Mean and standard deviation (m) of the individual (dx,dy,dz) coordinate discrepancies, the 2-d horizontal discrepancy vectors and the 3-d discrepancy vectors at each station.

- Maximums (m) of individual (dx,dy,dz) coordinate discrepancies, the 2-d horizontal discrepancy vector and the 3-d discrepancy vector at each station together with the corresponding station names.

- Comparison of coordinate discrepancies with specifications, including the following information for each station:

  - Station name;
  - 3-d distance (m) from the fixed station;
  - 2-d discrepancy (error) vector (m);
  - 2-d specifications for maximum allowable error at the specified confidence level;
  - Flag indicating whether the 2-d discrepancy vector is within the allowable error (passes) or outside the allowable error (fails);
  - 3-d discrepancy (error) vector (m);
  - 3-d specifications for maximum allowable error at the specified confidence level;
  - Flag indicating whether the 3-d discrepancy vector is within the allowed error (passes) or outside the allowable error (fails);

- Chi-square tests of station coordinate discrepancies (i.e., tests whether the coordinate discrepancies at each station are statstically difference from zero), including the following information for each station:

  - Station name;
  - Computed Chi-square statistic;
  - Out-of-context Chi-square limit for the specified confidence level;
  - Flag indicating result of out-of-context Chi-square test (pass or fail);
  - In-context Chi-square limit for the specified confidence level;
  - Flag indicating result of in-context Chi-square test (pass or fail);

- Chi-square tests of coordinate discrepancy sets for entire network, including the following information for each station:

  - Element tested (i.e., all dx (latitude), dy (longitude) or dz (height) coordinate components or all 2-d and 3-d discrepancy vectors);
  - Computed Chi-square statistic;
  - Out-of-context Chi-square limit for the specified confidence level;
  - Flag indicating result of out-of-context Chi-square test (pass or fail);
  - In-context Chi-square limit for the specified confidence level;
  - Flag indicating result of in-context Chi-square test (pass or fail);

All Chi-square tests of compatibility should pass if there are no incompatibilities between the two networks. Furthermore, none of the 2-d or 3-d discrepancy vectors should exceed the respective 2-d or 3-d specification limit. Strictly speaking, the specification of a 95% confidence limit means that 5% of the stations may exceed this limit. For the small test network used in the following examples, however, no stations should exceed the specification limit (i.e., 5% of 8 is less than one station).

EXAMPLE

The input data files and output listing of the example run of NETDIF in Figure 3 are given in the Appendix (see TEST1.DIF). This example assesses the first test network file TEST1.DAT with respect to the control (base) network file BASE.DAT.

Inspection of the output listing reveals that all statistical tests of compatibility fail for station 78X000. The comparison of the 2-d and 3-d error vectors are also larger than the maximum allowed for 1st order accuracy (the specification limits are derived from the distance from the fixed station). Clearly the position determined for this station is incompatible with the “known” control position and therefore should be rejected.

The reason for the large incompatibility at this station is the fact that the random errors used to create this simulation were very large at this point (specifically for the x and y components). The point is also very close to the fixed station (only 1.5 km) which results in smaller relative standard deviations for this position from the GPS adjustment as well as very small limits for the relative accuracy specification.

Only one other station failed any of the station-by-station tests. Station 77X002 failed to meet the 95% critical limit for the out-of-context Chi-square test although it did meet the critical limit for the in-context test. In practice, one would accept the in-context result and not reject this station.

Finally, the Chi-square tests on the different coordinate sets all failed to meet both the out-of-context and in-context tests, with the exception of only the test on the height components. This is expected since these tests include station 78X000 which is known to have large errors only in its x and y components. Thus all tests using these components should fail.

NETRAN
NETWORK DATUM TRANSFORMATION

METHODOLOGY

A Helmert transformation from the tested network solution to the control network can be used to quantify any network-wide systematic distortions in terms of seven transformation parameters (3 translations, 3 rotations and a scale change). The transformation parameters describe the differences in the datum of the test network with respect to the control (base) network.

To facilitate the interpretation of the datum transformation parameters, the coordinates are first transformed to the left-handed, topocentric (i.e., local geodetic) coordinate system with origin at the fixed station. The x, y and z axes may then be considered to be north, east and up, respectively, as defined at the fixed station. For example, a rotation about the z axis can be considered as a misorientation in azimuth.

The Helmert transformation of a single point is defined by

$$\mathbf{x}' = (1+s)\,\mathbf{R}\,\mathbf{x} + \mathbf{t}\,,$$

where

- $\mathbf{x}$ is the position vector of the (base) network point,
- $\mathbf{x}'$ is the position vector of the test network point,
- s is a scale change,
- $\mathbf{R}$ is a rotation matrix ($\mathbf{R}=\mathbf{R}x\mathbf{R}y\mathbf{R}z$ where $\mathbf{R}x$, $\mathbf{R}y$ and $\mathbf{R}z$ are rotations about the x-, y- and z-axes, respectively), and
- $\mathbf{t}$ is a translation vector.

The above implicit model is non-linear in the rotation parameters and can be rewritten as

$$\mathbf{f}(\mathbf{p},\mathbf{l}) = (1+s)\,\mathbf{R}\,\mathbf{x} + \mathbf{t} - \mathbf{x}' = \mathbf{0}\,,$$

where $\mathbf{p}$ is the vector of transformation parameters and $\mathbf{l}$ is the combined vector of positions from both the control and test networks (i.e., "observations"). The observations (positions) are also weighted using the covariance matrices associated with the coordinate estimates. A priori weights of the parameters may also be included in order to constrain some parameters to reasonable values.

Estimates of the parameters $\mathbf{p}$ are determined by linearizing the above model and solving for the parameters using a weighted least squares solution (see Vaníček and Krakiwsky [1986]). Let the linearized implicit model for all stations be represented by

$$\mathbf{A}\,\delta + \mathbf{B}\,\mathbf{r} + \mathbf{w} = \mathbf{0}\,,$$

where

- δ is the vector of corrections to the approximate values of the transformation parameters,
- **r** is the vector of residuals for both the control and test positions at all points,
- **A** is the first-order design matrix ($\mathbf{A}=\partial\mathbf{f}/\partial\mathbf{p}$) evaluated using the "observations" for each point and approximate values of the parameters,
- **B** is the second-order design matrix ($\mathbf{B}=\partial\mathbf{f}/\partial\mathbf{l}$) evaluated using the "observations" and approximate values of the parameters,
- **w** is the misclosure vector ($\mathbf{w}=\mathbf{f}(\mathbf{p},\mathbf{l})$) evaluated using the "observations" and approximate values of the parameters.

The least squares solution for corrections to the approximate values of the parameters is (Vaníček and Krakiwsky [1986])

$$\hat{\delta} = -(\mathbf{A}^T \mathbf{M} \mathbf{A} + \mathbf{C_x}^{-1})^{-1} \mathbf{A}^T \mathbf{M} \mathbf{w} ,$$

where $\mathbf{M}=(\mathbf{B}\mathbf{C_l}^{-1}\mathbf{B}^T)^{-1}$ and $\mathbf{C_x}$ and $\mathbf{C_l}$ are the a priori covariance matrices for the transformation parameters and observations (i.e., coordinates), respectively.

Because of the lack of knowledge about correlations among the a priori values of the parameters, their a priori covariance matrix is limited to only a diagonal matrix of variances which are supplied by the user. An identity matrix is used by default if no other values are specified. Usually the a priori parameter values will either be free (large variance) or fixed (small variance). Other intermediate weighting should not generally be used. The covariance matrix of the observations is given in the network data files.

The above solution is iterated and the parameters updated until their corrections become negligible. The present built in tolerance for iterating is $1\text{x}10^{-5}$ for the root mean square of the parameter corrections.

Once the transformation parameters are computed, they are used to transform the test network. The residual coordinate differences between the transformed test and control networks are then computed. Finally, a station-by-station Chi-square test is performed to test the statistical significance of these coordinate differences at each station. Letting $\Delta\mathbf{x}$ denote the coordinate differences at a single station, the Chi-square test is given by

$$\Delta\mathbf{x}^T \mathbf{C}\Delta\mathbf{x}^{-1} \Delta\mathbf{x} \leq \xi_{\chi^2_{3,1-\alpha}} ,$$

where $\xi_{\chi^2_{3,1-\alpha}}$ is the value from the Chi-square tables for 3 degrees of freedom (number of coordinate components per station) and the $1-\alpha$ confidence level. If $\Delta\mathbf{x}^T\mathbf{C}\Delta\mathbf{x}^{-1}\Delta\mathbf{x}$ is less then this critical limit, then the hypothesis that the coordinate differences are statistically equivalent to zero is accepted. If larger than the critical limit, the hypothesis is rejected and the test coordinates may be considered to be statistically incompatible with the control network.

The solution for the transformation parameters should be obtained first without constraining any of the parameters. The solution is then repeated, fixing the least statistically significant parameter to zero, until only statistically significant parameters remain at the 95% confidence level (i.e., until the free parameters are all larger than their 95% confidence interval; approximately 2 times the standard deviation).

If any statistically significant transformation parameters are discovered, an explanation for the datum difference should be found before continuing with the other analyses. The only acceptable reasons for such a discrepancy may be the use of incorrect coordinates for the fixed station or a different fixed station. Both cases may result in significant translation parameters and the transformed coordinates for the test network may be used in succeeding analyses.

NETRAN OPERATION

To run the NETRAN program enter the following command at the DOS prompt:

```
NETRAN
```

As soon as the program loads into memory, the program identification will be displayed and the user will be sequentially prompted to enter the name of the input data file for the control (base) network, the name of the input data file for the (test) network to be analysed, the name of the output listing file, the name of the output transformed data file for the test network, the type of reference ellipsoid and, optionally, the a priori transformation parameter values and standard deviations.

A typical session is illustrated in Figure 4. Each of the prompts will be discussed separately. In all cases, execution of the program may be terminated at any time by pressing the Ctrl and C (or Break) keys simultaneously.

```
Enter input data file for 1st (base) network >
```

Enter the name of the data file for the control (base) network. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

```
Enter input data file for 2nd (test) network >
```

Enter the name of the data file for the (test) network to be analysed. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

```
Enter output listing file >
```

Enter the name to use for the output listing file containing the results. If the file already exists, the program will display the following prompt .

```
***** File already exists.  Overwrite it? (Y,N) >
```

Enter `Y` if you wish to overwrite the existing file or `N` if not. If not overwriting the existing file, the program will prompt again for the output listing file.

```
-------------------------------------------------------
 NETRAN:  Network Helmert (Datum) Transformation
          Version 01 Feb 90
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

Enter input data file for 1st (base) network > base.dat

Enter input data file for 2nd (test) network > test2.dat

Enter output listing file > test2x.trn

Enter output (transformed) data file for 2nd network > test2x.dat

Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) > 83

Constrain the unknown parameters? (Y,N) > y

Enter a priori parameter values and standard deviations:
(Std.=0 => fixed, Std.=999 => free)

Rotation about x, std. (arcsec) > 0, 0

Rotation about y, std. (arcsec) > 0, 0

Rotation about z, std. (arcsec) > -10, 999

Translation in x, std. (metres) > -0.1, 999

Translation in y, std. (metres) > 0, 0

Translation in z, std. (metres) > 0, 0

Scale error, std. (ppm) > -2, 999

Reading data from 1st (base) network...
Reading data from 2nd (test) network...
Converting to topocentric coordinates...
Computing datum transformation parameters...
  Iteration          0
  Iteration          1
Solution converged, computing final iteration...
Computing statistics and writing to output file...
Transforming 2nd (test) network data...
Writing transformed data to output data file...
NETRAN finished.
```

Figure 4: Example NETRAN session (underscores indicate user input).

`Enter output (transformed) data file for 2nd network >`

Enter the name to use for the output data file containing the transformed test network. If the file already exists, the program will prompt to overwrite the file (see previous prompt). If no file is entered (i.e., only a carriage return), the program will not create a transformed data file. The transformed data file is normally created after the final run of NETRAN with only the statistically significant parameters left free.

```
Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) >
```

Select the type of reference ellipsoid used for the network data files by entering either `27` for NAD27, `83` for NAD83 or `0` to enter your own ellipsoid definition. If defining your own ellipsoid, the program will display the following prompts

```
Enter major semi-axis (m) >
Enter inverse flattening >
```

Enter the major semi-axis (in metres) and the inverse of the ellipsoid flattening (e.g., 294.9786982 for NAD27) to each of these prompts, respectively, in order to define the size and shape of the ellipsoid.

```
Constrain the unknown parameters? (Y,N) >
```

Enter either `Y` to constrain (i.e., fix) the parameters or `N` to treat them all as free. After choosing to constrain the parameters, the program will display the following prompts.

```
Enter a priori parameter values and standard deviations:
(Std.=0 => fixed, Std.=999 => free)
Rotation about x, std. (arcsec) >
Rotation about y, std. (arcsec) >
Rotation about z, std. (arcsec) >
Translation in x, std. (metres) >
Translation in y, std. (metres) >
Translation in z, std. (metres) >
Scale error, std. (ppm) >
```

For each transformation parameter the program prompts you to enter the appropriate a priori value and its corresponding a priori standard deviation in the stated units. These values may be separated by a blank space, comma, tab or carriage return. If constraining the values to those obtained from a previous run of NETRAN, use exactly the same values as computed (including sign). To fix a parameter to a specific value, you must use a zero standard deviation. To treat the parameter as free, enter either a very large standard deviation or simply 999 (the program will automatically use a large standard deviation).

After entering all of the required data, the program transforms the network coordinates to the local geodetic coordinate system at the fixed station, computes the least squares estimates of the datum transformation parameters, transforms the test network using the estimated datum parameters, computes the residual coordinate differences, performs a Chi-square test on the coordinate differences for each station, writes the results to the output listing file and, if a file name is supplied, creates the transformed test network data file for further processing.

INTERPRETATION OF RESULTS

The output provided by NETRAN includes the following information (see example file CCS2.TRN in the Appendix).

- Name of the 1st (base or control) network data file and its identifying character string (1st line in the data file).

- Name of the 2nd (test) network data file and its identifying character string (1st line in the data file).

- Name of the output transformed 2nd (test) network data file. This is left blank if no output data file was specified during input.

- Major semi-axis (m) and inverse flattening for the selected ellipsoid.

- A priori values and standard deviations for the constrained datum transformation parameters. These values are not listed if no constraints are requested.

- Station coordinates for both networks, including station number, latitude (deg, min, sec), longitude (deg, min, sec) and ellipoidal height (m) of each point.

- Chi-square test of the variance factor from the adjustment of the datum transformation parameters and its 95% confidence interval. If the computed variance factor falls outside the interval, the covariance matrix of the transformation parameters is multiplied by the estimated variance factor.

- Final estimates of the transformation parameters and their standard deviations for transforming the test network to the control (base) network. If the magnitude of any parameter is more than twice as large as its corresponding standard deviation, the parameter may be considered to be statistically significant at the 95% confidence level.

- Covariance matrix of the estimated parameters. Note that the result of the test of the variance factor determines whether or not this matrix is multiplied by the estimated variance factor. If the test fails, the covariance matrix is multiplied by the variance factor.

- Correlation matrix of the estimated parameters. Correlations between two parameters greater than about 0.9 indicate that the least squares solution is unable to distinguish between these parameters. Both parameters may be accounting for the same effect. Fix one of the parameters to zero by constraining it to a zero value and zero standard deviation during input.

- Coordinate differences between the transformed test network and the control network stations. Also listed is the the 3-d coordinate difference vector $r=\sqrt{\Delta x^2+\Delta y^2+\Delta z^2}$ for each station.

- Chi-square test of the coordinate misclosures at each station for the 95% confidence level. The success of the test for each station is indicated by the flag “Pass” or “Fail”.

If a minimally constrained adjustment has been performed with identical coordinates for the same fixed point, there should be no statistically significant datum transformation parameters. The existence of any datum differences could be caused by a number of factors, including the use of a different fixed point or coordinate system, an over-constrained adjustment or incorrect GPS ephemerides or incorrect GPS data processing. Assuming that a minimally constrained network adjustment was performed by the potential contractor and that the control network is based on NAD83, the only acceptable type of datum transformations would be translations resulting from the use of different coordinates for the fixed station or a different fixed station. In this case the transformed data file may be used for further testing. If any other type of transformation parameter is present, no further analyses should proceed until the cause of the datum differences is determined.

A possible example of an unacceptable datum parameter would be a scale error. The reduction of GPS observations are particularly susceptible to errors in the height of the fixed station. If the NAD27 height is used (which is different from the NAD83 value), a significant scale error could result. For example, an error of only 20 m in height corresponds to a scale error of approximately 1 ppm.

EXAMPLE

The input data files and output listing and transformed data file for two runs of NETRAN are given in the Appendix. These runs compare the perturbed test network file TEST2.DAT with the control network file BASE.DAT. The perturbed network has been transformed by a 0.1 m translation in the x (north) direction, a 10" rotation about the z (vertical) axis and a 2 ppm scale change. All coordinates have also been perturbed by equal random errors with zero mean and 0.03 m standard deviation.

The first run is made with all transformation parameters free. In the output listing TEST2.TRN the translation in x, the rotation about z and the scale error are correctly determined as statistically significant.

A second run was subsequently made where only the statistically significant parameters were held free (standard deviation 999 entered) at the values estimated by the first run and all others held fixed at zero (standard deviation 0 entered). The resulting parameters were estimated slightly better than in the first run as were the Chi-square tests of the station coordinate differences.

NETSTR / PLTSTR
NETWORK STRAIN ANALYSIS AND PLOTTING

METHODOLOGY

Strain analysis can be used to assess local systematic distortions of the test network with respect to the control (base) network. The local distortions are expressed in terms of strain at each station; specifically differential rotations and strain ellipses. At each point the differential rotation describes the local twisting while the strain ellipse represents both the direction and magnitude of any extension and/or contraction (i.e., local scale change with direction).

The strain analysis method employed by NETSTR is described in Craymer et al. [1987]. The technique involves computing the gradients (i.e., slopes) of a displacement surface defined by the position differences between the test and control networks. At each point a strain matrix is computed whose elements are the gradients of the displacement surface in the directions of the coordinate axes. The strain parameters are derived from this strain matrix.

NETSTR performs the strain analysis only in the horizontal dimension. The height component is ignored because of its poor determination in inherently 2-dimensional geodetic networks [Craymer et al., 1987]. Because geodetic networks essentially follow an ellipsoid, they have a very small range in the vertical dimension with respect to their often regional or continental proportions in the horizontal dimension.

The gradients at each point are determined by fitting separate plane surfaces (i.e., piece-wise planes) to each of the local geodetic Δx and Δy components of the local horizontal displacement field. The least squares solution for the slopes in the directions of the x and y axes are taken as the local gradients of the displacement field. The local displacement field for each point is defined as consisting of only those stations directly “connected” by observations to the station for which the strain is being computed. Strain determined in this way is referred to as piece-wise linear strain.

There are three coefficients defining each horizontal displacement plane: an intercept, the slope along the x axis and the slope along the y axis. In order to solve for these coefficients at least three displacements are needed, including the displacement at the station for which the strain is being computed. For the minimum 3 point configuration, the most reliable determination of strain occurs when the observation ties are at right angles to each other. The poorest determination occurs when they are oriented in the same direction (i.e., collinear). If these 3 or more defining points are on a straight line, strain in the direction perpendicular to that line is undefined (i.e., a singularity occurs).

Let $\Delta\mathbf{x}$ and $\Delta\mathbf{y}$ denote the x (north) and y (east) components of the local displacement field at a given point. The displacement planes are determined only from those stations directly connected to the given station. Two planes are fitted separately to the $\Delta\mathbf{x}$ and $\Delta\mathbf{y}$ displacements using the following models:

$$\Delta\mathbf{x} = e_{xo} + e_{xx}\,\mathbf{x} + e_{xy}\,\mathbf{y} ,$$

$$\Delta\mathbf{y} = e_{yo} + e_{yx}\,\mathbf{x} + e_{yy}\,\mathbf{y} ,$$

where e_{xo}, e_{xx} and e_{xy} are the coefficients of the plane approximating the $\Delta\mathbf{x}$ displacements and e_{yo}, e_{yx} and e_{yy} are those for the $\Delta\mathbf{y}$ coordinate differenecs.

The strain matrix at each point is given by the least squares estimates of the coefficients; i.e.,

$$\mathbf{E} = \begin{bmatrix} e_{xx} & e_{xy} \\ e_{yx} & e_{yy} \end{bmatrix} .$$

This is then decomposed into its symmetric **S** and anti-symmetric **A** parts defined as

$$\mathbf{S} = \begin{bmatrix} e_{xx} & \frac{1}{2}(e_{xy}+e_{yx}) \\ \frac{1}{2}(e_{xy}+e_{yx}) & e_{yy} \end{bmatrix} ,$$

$$\mathbf{A} = \begin{bmatrix} 0 & \frac{1}{2}(e_{xy}-e_{yx}) \\ -\frac{1}{2}(e_{xy}-e_{yx}) & 0 \end{bmatrix} = \begin{bmatrix} 0 & \omega \\ -\omega & 0 \end{bmatrix} .$$

The strain ellipse is derived from the symmetric part **S** using the diagonalization procedure of Jacobi. The eigenvalues of **S** may be either positive or negative (when negative the ellipse is a hyperbola). The length of the axes of the strain ellipse (or hyperbola) are equal to the eigenvalues (not their square root as is the case with error ellipses). The differential rotation is the upper off-diagonal element ω in the anti-symmetric part **A**. Note that the strain matrix is unitless since the components are gradients (i.e., m/m). Thus, the strain ellipse and differential rotation are also unitless (unitless rotations are equivalent to radians while unitless strains are simply called “strains”).

Once the strain parameters are computed for all stations they can be plotted. In order to determine whether the strain parameters are determined weakly, the observation ties should be displayed and checked to see if any large strains are due to their poor geometric configuration. Strain ellipses are plotted as ellipses at each station. The colours of the axes denote when the strain is positive or negative. Positive strain axes (elongation or positive scale change) are blue while negative strain axes (contraction or negative scale change) are red. Differential rotations are displayed as rotation arcs (i.e., sectors of a circle). The larger the arc, the larger the differential rotations. Positive rotations are plotted clockwise from the top and negative rotations counter-clockwise (i.e., following the usual azimuth convention). The scales of both the largest strain ellipse and differential rotation are given at the bottom of the plot.

NETSTR OPERATION

To run the NETSTR program enter the following command at the DOS prompt:

```
NETSTR
```

As soon as the program loads into memory, the program identification will be displayed and the user will be sequentially prompted to enter the name of the input data file for the control (base) network, the name of the input data file for the (test) network to be analysed, the name of the output listing file, the name of the output plot data file and the type of reference ellipsoid.

A typical session is illustrated in Figure 5. Each of the prompts will be discussed separately. In all cases, execution of the program may be terminated at any time by pressing the Ctrl and C (or Break) keys simultaneously.

```
-------------------------------------------------------
 NETSTR:  Network Strain Analysis
          Version 01 Feb 90
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

Enter input data file for 1st (base) network > base.dat

Enter input data file for 2nd (test) network > test1.dat

Enter output listing file > test1.str

Enter output plot data file > test1.plt

Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) > 83

Enter specified order of accuracy (1=1st, 2=2nd, 3=3rd) > 1

Reading data for 1st (base) network...
Reading data for 2nd (test) network...
Finding common stations and sorting data...
Computing piece-wise linear strain parameters...
*** Warning *** PWL: Insufficient ties for solution
                Station          5
                Strain elements set to zero
*** Warning *** PWL: Insufficient ties for solution
                Station          8
                Strain elements set to zero
Writing results to output listing file...
Writing strain data to plot file...
NETSTR finished.
```

Figure 5: Example NETSTR session (underscores indicate user input).

`Enter input data file for 1st (base) network >`

Enter the name of the data file for the control (base) network. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

`Enter input data file for 2nd (test) network >`

Enter the name of the data file for the (test) network to be analysed. If the file cannot be found or is entered incorrectly, the program will display an error message and prompt for another file name.

```
Enter output listing file >
```

Enter the name to use for the output listing file containing the results. If the file already exists, the program will display the following prompt .

```
***** File already exists.  Overwrite it? (Y,N) >
```

Enter `Y` if you wish to overwrite the existing file or `N` if not. If not overwriting the existing file, the program will prompt again for the output listing file.

```
Enter output plot data file >
```

Enter the name to use for the output plot data file containing the results to be plotted by the PLTSTR program. If the file already exists, the program will prompt to overwrite it in the same manner as for the output listing file.

```
Enter ellipsoid (27=NAD27, 83=NAD83, 0=User Defined) >
```

Select the type of ellipsoid used for the network data files by entering either `27` for NAD27, `83` for NAD83 or `0` to enter your own ellipsoid definition. If defining your own ellipsoid, the program will display the following prompts

```
Enter major semi-axis (m) >
Enter inverse flattening >
```

Enter the major semi-axis (in metres) and the inverse of the ellipsoid flattening (e.g., 294.9786982 for NAD27) to each of these prompts, respectively, in order to define the size and shape of the ellipsoid.

```
Enter specified order of accuracy (1=1st, 2=2nd, 3=3rd) >
```

Enter the desired order of accuracy to use in determining the maximum allowable size of the 95% confidence regions. The specified maximum errors for each of these orders are based on the 2-d 95% confidence ellipse as defined by Surveys and Mapping Branch [1978]. See the NETREG Methodology section for 1-d and 3-d limits.

After entering all of the required data, the program computes the strain parameters for each station, writes the results to the output listing file and also writes the strain data to the output plot data file. When there are fewer than 2 different observation ties into a station, it is not possible to fit a plane surface to the displacements at that point. NETSTR reports this case with a warning message and sets the strains to zero for the station. For the example in Figure 5 the following warning message is displayed because there are not enough different observation ties to stations 5 and 8:

```
*** Warning *** PWL: Insufficient ties for solution
                Station          5
                Strain elements set to zero
*** Warning *** PWL: Insufficient ties for solution
                Station          8
                Strain elements set to zero
```

Note that the station number given in these warning messages is not the same as the actual station name of the point. Both station numbers and and station names are given in the output listing.

PLTSTR OPERATION

To run the PLTSTR program enter the following command at the DOS prompt:

```
PLTSTR
```

As soon as the program loads into memory, the program's main menu will be displayed as shown in Figure 6.

PLTSTR is completely menu driven and requires no special operating instructions with the exception that the input plot data file must have been created by the NETSTR program. The program will warn the user whenever an invalid operation is requested. For example, it is not possible to display or list any information until a network is read in. Execution of the program may be terminated at any time by pressing the Ctrl and C (or Break) keys simultaneously or by issuing the “Q” command in the main menu.

Output may be sent to either the computer screen (the default), an Epson dot matrix printer connected to the LPT1 parallel port or to a Hewlett-Packard LaserJet Series II laser printer connected to the LPT2 port. Other output devices are also supported by entering the “ioport” and “model” codes for the PLOTWORKS, Inc. PLOT88™ graphics library. To select an output device other than the computer screen, enter the “C” command in the main menu to change the plotting device. Note that an EGA graphics adapter is required to plot to the computer screen. A colour monitor is also required to distinguish between positive and negative strain ellipse axes.

```
----------------------------------------------------
 PLTSTR:  Plots Results from Program NETSTR
          Version 01 Feb 90
 Copyright (c) 1990 Geodetic Research Services Ltd.
----------------------------------------------------

Available commands:

  R  - Read plot data                    L  - List results to a file
  PS - Plot stations and Ties            LS - List stations and ties
  PD - Plot displacements in x,y,z       LD - List displacements in x,y,z
  PR - Plot differential Rotations       LR - List differential rotations
  PE - Plot strain Ellipses              LE - List strain ellipses
  C  - Change plotting device            Q  - Quit

Command > _
```

Figure 6: Main menu for PLTSTR.

PLTSTR was designed to handle 3-d strain analyses. Space is therefore provided in the various screen listings for strain in the vertical dimension. For the 2-d horizontal strains provided by NETSTR, this information is automatically set to zero.

When graphically displaying different quantities (e.g., displacements, strain ellipses, differential rotations), the following supplemental information is provided on the plot:

- station name next to each point;
- latitude and longitude grid in decimal degrees along the bottom and left side of the plot, respectively;
- scale for the parameters at the bottom of the display in terms of the size and units corresponding to the maximum value of parameter(s) being displayed;

Strain ellipses are plotted as ellipses while differential rotations are plotted as rotation arcs (sectors of a circle) as discussed in the "Methodology" section.

INTERPRETATION OF RESULTS

The output provided by NETSTR includes the following information (see example file CCS1.STR and CCS1.PLT).

- Type of strain solution (piece-wise linear approximation with connected stations is automatically used in this application; it cannot be changed).
- Name of the 1st (base or control) network data file and its identifying character string (1st line in the data file).
- Name of the 2nd (test) network data file and its identifying character string (1st line in the data file).
- Major semi-axis (m) and inverse of flattening for the selected ellipsoid.
- List of station coordinates from 1st control (base) network including latitude (deg, min, sec), longitude (deg, min, sec) and ellipsoidal (i.e., geodetic) height (m).
- List of coordinate discrepancies (i.e., differences) of test network with respect to the control (base) network (i.e., test-base network) including differences in latitude (sec), longitude (sec), ellipsoid height (m), local geodetic x (m) and local geodetic y (m).
- List of strain matrices for all stations in units of strains (1 str = 1 m/m = $1x10^6$ ppm).
- List of strain parameters including the following information for each station:
    - Station number;
    - Station name;
    - 2-d specification for maximum relative error (ppm) for the specified order of accuracy;
    - Differential rotation (µstrains = ppm = $1x10^{-6}$ radians);
    - Flag indicated whether the differential rotation is within the allowable relative error (passes) or outside the allowed relative error (fails);
    - Lengths (µstrains = ppm) and azimuth (deg) of the major and minor semi-axes of the strain ellipse;

- Flag indicated whether the absolute value of the major and minor semi-axes are within the allowable relative error (passes) or outside the allowed relative error (fails).

All of the strain parameters should be smaller in absolute value than the relative accuracy for the specified order of accuracy. Local distortions at a station are indicated by relatively large strain parameters at that station (i.e., strain parameters that are significantly larger than the others in the network). Consistently large differential rotations at all stations indicate a common rotation of all stations (i.e., the test network is rotated by that amount with respect to the control network). Large strain ellipses at all stations similarly indicate the presence of a common scale error in the test network with respect to the control network (i.e., the test network is mis-scaled by that amount with respect to the control network). These network-wide distortions should agree with those determined from the Helmert transformation program NETRAN.

EXAMPLE

Input and output files for two examples of NETSTR runs are provided in the Appendix. The first example assesses the distortions that the test network TEST1.DAT must undergo to fit the control (base) network BASE.DAT. The coordinates in TEST1.DAT are perturbed from those in BASE.DAT by the addition of a random errors with zero mean and 0.03 m standard deviation. The output from NETSTR for this comparison are in the files TEST1.STR (listing) and TEST1.PLT (plot data file for PLTSTR).

From the output listing and plots it is apparent that the distortions are much larger at stations 78X000 and 89X005. Both the differential rotations and strain ellipses exceed 100 radians or 100 ppm ($0.1x10^{-3}$ str) in magnitude. The other stations exhibit strain ellipses of a common magnitude and orientation (scale errors) of about +3 ppm ($0.3x10^{-5}$) in the east direction and about –2 ppm ($0.2x10^{-5}$) in the north direction. Note that there were insufficient ties to compute strain at stations 89X002 and 89X006.

Although the large distortions at station 78X000 is supported by the statistical compatibility tests in NETDIF, the large distortions at station 89X005 is actually a result of the poor determination of the strain elements. An inspection of the plot of observation ties reveals that the ties into station 89X005 are almost collinear. Fitting a plane to three points almost lying on a straight line results in a very weak determination of strain in the direction perpendicular to the ties. This is exactly what is seen in this example and emphasises the importance of checking the orientation of the ties into each station.

The second example illustrates the effect of network-wide distortions on the strain parameters by examining the distortions in the TEST2.DAT test network file with respect to the control network file BASE.DAT. The TEST2.DAT coordinates have been transformed from the BASE.DAT positions using a 0.1 m translation along the x-axis, a 10" rotation about the z-axis (i.e., in azimuth) and a 2 ppm scale error. All coordinates are also perturbed by common random errors of zero mean and 0.03 m standard deviation. The output from NETSTR is given in the Appendix in the files TEST2.STR and TEST2.PLT.

As before, the distortions at stations 0 and 5 are very large with respect to the other stations. The differential rotations are about 10" ($0.48x10^{-3}$ rad) and the strain ellipses exhibit scale errors of about 300 ppm (–0.3x10–3 str) in the direction of 127° and about

–600 ppm (–0.6x10^{-3} str) in the direction of 37°. As discussed above, the strain at station 89X005 is only an artifact of the poor orientation of the observation ties at this point.

At all other stations the differential rotations listed in output file TEST2.STR exhibit the large values as expected. That is, the test network is rotated about the fixed station by 10" (0.48x10^{-4} rad) with respect to the control network. The strain ellipses for these stations also display scale errors of about 2 ppm These results agree exactly with the actual distortions introduced as well as with the results from NETRAN. Note that NETRAN gives the parameters required to transform the test network to the control network. These are of opposite sign to the actual transformation used to generate the test network (which are given by the strain analysis).

TECHNICAL SUPPORT

Should you encounter any problems or have suggestions for improving this software, please call or write Geodetic Research Services at the following address:

Geodetic Research Services Limited
P.O. Box 3643, Station B
Fredericton, New Brunswick, Canada
E3A 5L7

Telephone (506) 458-9434
Telefax(506) 453-4943

Before reporting any possible problems please read this manual carefully. If no explanation of the problem can be found in the manual, please re-copy the programs from the original distribution disk (see Installation section of this manual). To verify that the programs are operating correctly, test each of the examples provided and check that the results agree with those given in the Appendix. **Please note that we are unable to support modified versions of our original software.**

If you are unable to resolve some problems, please send us the following information:

- description of the conditions under which the problem occurs (e.g., type of computer, amount of available RAM, free disk space, any “terminate and stay resident” programs or drivers);
- input network data files that cause the problem;
- program options used to generate the problem;
- copy of the program you are experiencing the problem with;
- address, telephone, and if possible, telefax numbers at which you can be reached.

ACKNOWLEDGEMENTS

Many people contributed to the development of this software. We especially thank Prof. David Wells and Mr. Phillip Rapatz who developed and/or contributed to some of the original versions of these programs. We also acknowledge the Canadian Geodetic Survey for use of parts of the strain analysis portion of their network analysis software NETAN. A substantially modified portion of this was used in the development of NETSTR.

The first version of this software was developed primarily for the Land Information Systems Division of Alberta Forestry, Lands and Wildlife. In particular we thank Craig Barnes who was instrumental in establishing what is probably the first dedicated GPS validation network in the world. We also extend our appreciation to Roy Devlin of the City of Edmonton for his past support.

Finally we thank Phil MacKenzie and Anil Sanji, both of Alberta Forestry, Lands and Wildlife, whose comments on the first version of the software and manual were greatly appreciated. We also acknowledge Dr. Alfred Kleusberg and Prof. Richard Langley for many fruitful discussions concerning all aspects of specifications for, and the evaluation of, GPS networks.

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Surveys and Mapping Branch (1978). Specifications and recommendations for control surveys and survey markers. Energy, Mines and Resources Canada, Surveys and Mapping Branch, Ottawa.

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APPENDIX
EXAMPLE INPUT AND OUTPUT FILES

BASE.IOB

Input file for GeoLab™ adjustment of GPS baseline observations from CCS 1990 GPS validation survey.

```
0  0 21       111 1 1 2                       00 0 0 00      0.001 95.000
 80   6378137.000  298.257222101

 24   77X251                       -1493875.5960  -3489883.3120   5109062.6060
 24   78X000                       -1495211.5080  -3489300.2280   5109051.9080
 24   89X001                       -1486206.6529  -3493356.0574   5108965.3904
 24   89X002                       -1491976.5318  -3482183.4193   5114748.4641
 24   89X003                       -1447410.1657  -3509952.1565   5108673.3207
 24   89X006                       -1529136.8216  -3559956.3161   5050440.0075
 24   89X005                       -1586472.0501  -3445996.3022   5111028.2182
 24   89X004                       -1476292.4648  -3451887.3015   5139603.6361
*24   786561                       -1494054.7830  -3521563.3261   5087487.9044
*24   776102                       -1512864.9325  -3442686.1176   5135279.0849

       control# 1
 892dc
 96   77X251                          N53 34 14.38388W113 10 25.59619 684.9443
 97POVDIAGONAL
 98     0.000001           0.000001
      ]
       control# 1
 45   77X251                                               684.94434   0.0001
      ]
  0DAY171 - GPSPHA8.OUT - L3 AMBIGUITIES FIXED                     4JAN9015:25
  0   GPS SET #  1
  0         --> CORFILE =GPSPHA8.XYZ
  0         --> COVFILE =GPSPHA8.COV
 913DD
 92   77X251                       -1493875.5960  -3489883.3120   5109062.6060
 92   78X000                       -1495211.4984  -3489300.1773   5109051.9595
 92   89X001                       -1486206.6529  -3493356.0574   5108965.3904
 92   89X002                       -1491976.5318  -3482183.4193   5114748.4641
 97PDVUPPER
 98  0.741796459976E-06  0.453878091762E-06 -0.598190307405E-06
 98  0.363860093749E-06  0.222577184350E-06 -0.293961875838E-06
 98  0.369962199059E-06  0.226682895947E-06 -0.298501259566E-06
 98  0.163248532904E-05 -0.116266039366E-05  0.222944807325E-06
 98  0.794401411514E-06 -0.556477650802E-06  0.226644582507E-06
 98  0.820794778514E-06 -0.575578261262E-06
 98  0.205797538003E-05 -0.294327864442E-06 -0.556229922565E-06
 98  0.994063564366E-06 -0.298743710848E-06 -0.576163722570E-06
 98  0.102153213195E-05
 98  0.734019704211E-06  0.450550556914E-06 -0.594193407720E-06
 98  0.363883649642E-06  0.223038354264E-06 -0.294207824698E-06
 98  0.160467226517E-05 -0.112427926239E-05  0.222639019803E-06
 98  0.794528300438E-06 -0.555937899229E-06
 98  0.200252635370E-05 -0.294081252115E-06 -0.556727939205E-06
 98  0.993858159413E-06
 98  0.745114770171E-06  0.455449591362E-06 -0.600401447853E-06
 98  0.163915003344E-05 -0.117033514256E-05
 98  0.207773524534E-05
```

```
       ]
 0DAY172 - GPSPHA9.OUT - L3  ALL AMBIGUITIES FIXED                15JAN9017:23
 0   GPS SET #  1
 0          --> CORFILE =GPSPHA9.XYZ
 0          --> COVFILE =GPSPHA9.COV
913DD
92   89X004                        -1476292.4648  -3451887.3015   5139603.6361
92   89X003                        -1447410.1259  -3509952.0470   5108673.3327
97PDVUPPER
98  0.155466890693E-04  0.955703146378E-05 -0.127683074838E-04
98  0.340097052071E-04 -0.240688687405E-04
98  0.435900205717E-04
       ]
 0DAY174 - GPSPHA6.OUT -  ALL AMBIGUITIES FIXED                    8JAN9015:51
 0   GPS SET #  1
 0          --> CORFILE =GPSPHA6.XYZ
 0          --> COVFILE =GPSPHA6.COV
913DD
92   78X000                        -1495211.5080  -3489300.2280   5109051.9080
92   89X005                        -1586472.0501  -3445996.3022   5111028.2182
92   89X001                        -1486206.6984  -3493356.0245   5108965.3062
97PDVUPPER
98  0.296728535042E-04  0.191770746276E-04 -0.248618481368E-04
98  0.151425617661E-04  0.101984595522E-04 -0.129598944784E-04
98  0.667254220490E-04 -0.475423550477E-04  0.103809638522E-04
98  0.360361093606E-04 -0.255912053801E-04
98  0.820956425094E-04 -0.131410178962E-04 -0.255062866953E-04
98  0.426500346855E-04
98  0.299539170837E-04  0.194263966098E-04 -0.252268269406E-04
98  0.675435753541E-04 -0.477509730988E-04
98  0.824859261188E-04
       ]
 0DAY175 - GPSPHA8.OUT - L3  ALL AMBIGUITIES FIXED                 9JAN9015:31
 0   GPS SET #  1
 0          --> CORFILE =GPSPHA8.XYZ
 0          --> COVFILE =GPSPHA8.COV
913DD
92   89X001                        -1486206.6529  -3493356.0574   5108965.3904
92   89X004                        -1476292.4648  -3451887.3015   5139603.6361
92   89X005                        -1586472.1266  -3445996.2344   5111028.3726
97PDVUPPER
98  0.334934010053E-04  0.204176179098E-04 -0.259402505978E-04
98  0.144548813363E-04  0.903906019840E-05 -0.120045972480E-04
98  0.667573039575E-04 -0.480622169725E-04  0.880984469569E-05
98  0.312522125504E-04 -0.223573991047E-04
98  0.837876102008E-04 -0.116839664123E-04 -0.223127482505E-04
98  0.400548273974E-04
98  0.298398266378E-04  0.184631771148E-04 -0.246060048297E-04
98  0.641239852816E-04 -0.459072564017E-04
98  0.823277670666E-04
       ]
 0DAY177 - GPSPHA27.OUT - L3   ALL AMBIGUITIES FIXED   *#2*       11JAN9009:31
 0   GPS SET #  1
 0          --> CORFILE =GPSPHA27.XYZ
 0          --> COVFILE =GPSPHA27.COV
913DD
92   77X251                        -1493875.5960  -3489883.3120   5109062.6060
92   89X002                        -1491976.5492  -3482183.4104   5114748.4855
92   89X003                        -1447410.2848  -3509952.1131   5108673.3640
92   89X006                        -1529135.9356  -3559957.5787   5050439.4014
97PDVUPPER
98  0.341843066803E-05  0.271480337436E-05 -0.402964060212E-05
98  0.169858368848E-05  0.130794718124E-05 -0.199904395488E-05
98  0.169412403277E-05  0.130711507682E-05 -0.200876520610E-05
```



```
98  0.352950631657E-04 -0.695283047968E-05  0.132955202415E-05
98  0.172772479789E-04 -0.340176859352E-05  0.130217410521E-05
98  0.172309514296E-04 -0.343665010234E-05
98  0.134272191466E-04 -0.201014527094E-05 -0.338779934325E-05
98  0.665355718594E-05 -0.199260574428E-05 -0.338170452931E-05
98  0.666512862404E-05
98  0.342020064809E-05  0.266117865905E-05 -0.404759056066E-05
98  0.169689510417E-05  0.132316149915E-05 -0.201871656048E-05
98  0.348437196001E-04 -0.686690808635E-05  0.129712565671E-05
98  0.172402180539E-04 -0.342917995486E-05
98  0.134926089245E-04 -0.199127106649E-05 -0.338752289129E-05
98  0.666755175470E-05
98  0.341700596631E-05  0.262879968763E-05 -0.404666550154E-05
98  0.344253849208E-04 -0.689545650485E-05
98  0.134190503329E-04
       ]
 0DAY181 - GPSPHA3.OUT - L3 AMBIGUITIES FIXED                      6JAN9010:05
 0   GPS SET #  1
 0          --> CORFILE =GPSPHA3.XYZ
 0          --> COVFILE =GPSPHA3.COV
913DD
92   77X251                       -1493875.5960  -3489883.3120   5109062.6060
92   78X000                       -1495211.4998  -3489300.1677   5109051.9440
92   89X001                       -1486206.6642  -3493356.0469   5108965.3842
92   89X002                       -1491976.5209  -3482183.4018   5114748.4399
97PDVUPPER
98  0.660684090633E-06  0.402601537036E-06 -0.526350072035E-06
98  0.315141433540E-06  0.194191950468E-06 -0.255819975506E-06
98  0.327642395962E-06  0.200552775797E-06 -0.262201080083E-06
98  0.140716070788E-05 -0.100477856102E-05  0.194524704418E-06
98  0.674036966541E-06 -0.487699704414E-06  0.200524635689E-06
98  0.697660932485E-06 -0.500082180543E-06
98  0.177357042587E-05 -0.256147887840E-06 -0.487515853276E-06
98  0.864010055164E-06 -0.262411388984E-06 -0.500550147577E-06
98  0.882844525657E-06
98  0.632620615961E-06  0.390137163427E-06 -0.513561043367E-06
98  0.315167132332E-06  0.194607815075E-06 -0.256048557381E-06
98  0.135151662814E-05 -0.977283772173E-06  0.194248667408E-06
98  0.674164297584E-06 -0.487296123378E-06
98  0.173301281615E-05 -0.255927513110E-06 -0.487935338589E-06
98  0.863868730300E-06
98  0.664707933785E-06  0.405343954224E-06 -0.530345123019E-06
98  0.141501320538E-05 -0.100946096214E-05
98  0.178288911156E-05
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99
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BASE.ADJ

Data file of adjusted positions and covariance matrix from GeoLab™ adjustment. Created by GeoLab™ TOOLKIT program for use as position observations in a subsequent GeoLab™ adjustment (i.e., integration).

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953dc  Adjusted 3-D Coordinates.
96   89X003                         N53 3353.848369W112 2435.782868 669.7945
96   77X251                         N53 3414.383880W113 1025.596190 684.9443
96   78X000                         N53 3414.442151W113 1144.794691 670.3740
96   89X004                         N54  2 9.944093W113  918.999924 616.9170
96   89X002                         N53 3927.231365W113 1135.518923 619.8859
96   89X005                         N53 3557.847407W114 4313.645244 767.8036
96   89X001                         N53 34 7.729003W113  248.293765 715.9835
96   89X006                         N52 4130.623004W113 1443.244320 763.8323
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98    7.026961690e-004   -2.600787731e-004   -3.716029587e-004
98    1.147835303e-004   -3.048932248e-006   -5.709759481e-006
98    2.486278254e-004   -7.353741006e-005   -8.561083944e-005
98    1.124783442e-004   -4.193215670e-006   -5.993240368e-006
98    4.211391522e-004   -1.432134107e-004   -2.037904077e-004
98    4.579996559e-004    2.117978395e-004    1.074716782e-006
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98    3.315311130e-004    1.298121401e-004   -3.982915933e-007
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98    1.605655864e-004    2.751977921e-005   -2.112353121e-006
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98    2.252005237e-004    7.043297173e-005
98    1.819417002e-003   -5.720789742e-009    7.933062809e-007
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98    2.979008017e-004   -6.089562833e-006    1.375644802e-006
98    4.419802648e-005   -1.863440956e-004    7.955423185e-005
98    6.305216227e-004
98    1.001968974e-004    7.344502925e-020    2.158110218e-022
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98    1.001967380e-004    1.787338586e-007   -3.115065705e-009
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98	1.094582663e-004	-5.798555162e-007	-1.845723036e-006
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98	1.149515075e-004	-3.878404835e-006	-1.799517910e-006
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98	1.477747040e-004	-5.578045264e-006	-8.225278533e-007
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98	7.075838084e-005	-7.427842560e-006	-6.810047450e-007
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98	7.147013388e-005	-2.770257988e-006	-5.837680287e-007
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98	1.147724983e-004	-1.851343143e-006	-6.388168824e-006
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98	6.890794222e-005	-4.417850120e-006	-1.546116216e-006
98	7.062142480e-005		
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98	1.232402710e-004	2.759695856e-007	-1.022442109e-005
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98	1.109336307e-004	-2.844529889e-005	8.926711329e-006
98	1.226273694e-004		
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98	1.088696417e-004	-1.922793484e-006	-5.663218412e-006
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98	1.065238670e-004	-4.313342938e-007	
98	1.436095677e-004	-3.199186215e-006	-2.101323934e-007
98	3.777252457e-005		
98	1.364945478e-003	-5.905316705e-004	-7.948485109e-004
98	5.715701623e-004	3.562535433e-004	
98	2.097677055e-003		

BASE.DAT

Network data file in NETVAL format for actual CCS 1990 GPS validation survey. Created by NETDAT from BASE.IOB and BASE.ADJ

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CCS 1990 GPS Validation Survey
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 89X003     53 33 53.848369    -112 24 35.782868     669.7945     669.7945
 77X251     53 34 14.383880    -113 10 25.596190     684.9443     684.9443
 78X000     53 34 14.442151    -113 11 44.794691     670.3740     670.3740
 89X004     54  2  9.944093    -113  9 18.999924     616.9170     616.9170
 89X002     53 39 27.231365    -113 11 35.518923     619.8859     619.8859
 89X005     53 35 57.847407    -114 43 13.645244     767.8036     767.8036
 89X001     53 34  7.729003    -113  2 48.293765     715.9835     715.9835
 89X006     52 41 30.623004    -113 14 43.244320     763.8323     763.8323
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  -0.5820234740E-03   0.2117978395E-03   0.1819417002E-02
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  -0.1074637806E-05   0.1001879936E-03   0.7933062809E-06   0.7344502925E-19
   0.1001968974E-03
   0.1422932303E-09  -0.7931992871E-08   0.1001937567E-05   0.2158110218E-21
   0.5232666027E-22   0.1001968974E-05
   0.1098978839E-03  -0.7132286043E-06  -0.4539966315E-05   0.1001968926E-03
   0.3095428112E-07  -0.2477728917E-12   0.1304420185E-03
  -0.3212531457E-05   0.1069448950E-03   0.7980759139E-06  -0.3095427466E-07
   0.1001968900E-03   0.2284593394E-09  -0.2895809243E-05   0.1254061407E-03
  -0.4377442665E-05  -0.6338270328E-06   0.3987316157E-04   0.3183518521E-10
  -0.2284592519E-07   0.1001968948E-05  -0.1276451447E-04  -0.3402756547E-05
   0.1477747040E-03
   0.7026961690E-03  -0.2484577125E-03  -0.3769975492E-03   0.1001935881E-03
  -0.2618395872E-07  -0.8139225184E-08   0.1125869098E-03  -0.2093560479E-05
  -0.5578045264E-05   0.1366082722E-02
  -0.2600787731E-03   0.3315311130E-03   0.1390385441E-03   0.2602876457E-07
   0.1001968922E-03  -0.1921064029E-09  -0.1920726576E-05   0.1094582663E-03
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  -0.3716029587E-03   0.1298121401E-03   0.1162939357E-02   0.8139274962E-06
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  -0.3619574121E-05   0.1240096030E-03
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   0.1146245826E-03  -0.1802716417E-05  -0.4417850120E-05   0.1535349576E-03
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  -0.3199186215E-05   0.1364945478E-02
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  -0.5837680287E-06  -0.8736383508E-04   0.1823610498E-03   0.4845204643E-04
  -0.1795798220E-05   0.1120379632E-03  -0.1546116216E-05  -0.1950023751E-04
   0.1245004665E-03   0.8926711329E-05  -0.1922793484E-05   0.1065238670E-03
  -0.2101323934E-06  -0.5905316705E-03   0.5715701623E-03
  -0.2037904077E-03   0.7043297173E-04   0.6305216227E-03  -0.1536756257E-05
  -0.7585802227E-07   0.1001850831E-05  -0.5236995239E-05  -0.5458372760E-06
   0.3693979669E-04  -0.1333241566E-03   0.4603040548E-04   0.4114005334E-03
  -0.8017249199E-05  -0.1454599414E-05   0.7062142480E-04  -0.3366601298E-04
   0.1449260104E-04   0.1226273694E-03  -0.5663218412E-05  -0.4313342938E-06
   0.3777252457E-04  -0.7948485109E-03   0.3562535433E-03   0.2097677055E-02
 14
 91     77X251     78X000
 91     77X251     89X001
 91     77X251     89X002
 91     89X004     89X003
 91     78X000     89X005
 91     78X000     89X001
 91     89X001     89X004
 91     89X001     89X005
 91     77X251     89X002
 91     77X251     89X003
 91     77X251     89X006
 91     77X251     78X000
 91     77X251     89X001
 91     77X251     89X002
```

TEST1.DAT

BASE.DAT network data file with 0.03 m random error.

```
Perturbed CCS 1990 GPS Validation Survey: 0.03m random error
  8     77X251
 89X003         53 33 53.847251    -112 24 35.780517     669.8179     669.8179
 77X251         53 34 14.383880    -113 10 25.596190     684.9443     684.9443
 78X000         53 34 14.443935    -113 11 44.790261     670.3996     670.3996
 89X004         54  2  9.944144    -113  9 18.998610     616.9076     616.9076
 89X002         53 39 27.232182    -113 11 35.520232     619.9242     619.9242
 89X005         53 35 57.846360    -114 43 13.645399     767.8207     767.8207
 89X001         53 34  7.729967    -113  2 48.294392     715.9778     715.9778
 89X006         52 41 30.622110    -113 14 43.244610     763.7994     763.7994
 1.0
   0.1064811164E-02
  -0.4077391926E-03   0.4579996559E-03
  -0.5820234740E-03   0.2117978395E-03   0.1819417002E-02
   0.1001911334E-03   0.1074716782E-05  -0.5720789742E-08   0.1001968974E-03
  -0.1074637806E-05   0.1001879936E-03   0.7933062809E-06   0.7344502925E-19
   0.1001968974E-03
   0.1422932303E-09  -0.7931992871E-08   0.1001937567E-05   0.2158110218E-21
   0.5232666027E-22   0.1001968974E-05
   0.1098978839E-03  -0.7132286043E-06  -0.4539966315E-05   0.1001968926E-03
   0.3095428112E-07  -0.2477728917E-12   0.1304420185E-03
  -0.3212531457E-05   0.1069448950E-03   0.7980759139E-06  -0.3095427466E-07
   0.1001968900E-03   0.2284593394E-09  -0.2895809243E-05   0.1254061407E-03
  -0.4377442665E-05  -0.6338270328E-06   0.3987316157E-04   0.3183518521E-10
  -0.2284592519E-07   0.1001968948E-05  -0.1276451447E-04  -0.3402756547E-05
   0.1477747040E-03
   0.7026961690E-03  -0.2484577125E-03  -0.3769975492E-03   0.1001935881E-03
  -0.2618395872E-07  -0.8139225184E-08   0.1125869098E-03  -0.2093560479E-05
  -0.5578045264E-05   0.1366082722E-02
  -0.2600787731E-03   0.3315311130E-03   0.1390385441E-03   0.2602876457E-07
   0.1001968922E-03  -0.1921064029E-09  -0.1920726576E-05   0.1094582663E-03
  -0.8225278533E-06  -0.2276074730E-03   0.9945120795E-03
  -0.3716029587E-03   0.1298121401E-03   0.1162939357E-02   0.8139274962E-06
   0.1899856813E-07   0.1001935897E-05  -0.4313784655E-05  -0.5798555162E-06
   0.5524838920E-04  -0.6343840065E-03  -0.4994693104E-04   0.5025892127E-02
   0.1147835303E-03  -0.3982915933E-06  -0.6248255627E-05   0.1001967784E-03
   0.2735945619E-07  -0.1519685682E-08   0.1150238074E-03  -0.1845723036E-05
  -0.6518548666E-05   0.1147724983E-03  -0.1672229734E-05  -0.5302752050E-05
   0.1300400325E-03
  -0.3048932248E-05   0.1119839277E-03  -0.4902050834E-06  -0.2732889494E-07
   0.1001968917E-03   0.2017020703E-09  -0.1841544295E-05   0.1119746674E-03
  -0.1369138240E-05  -0.1851343143E-05   0.1118767353E-03  -0.1396131709E-05
  -0.3619574121E-05   0.1240096030E-03
  -0.5709759481E-05  -0.2302415768E-05   0.7044761014E-04   0.1519740671E-06
  -0.2012873336E-07   0.1001967801E-05  -0.6210461874E-05  -0.1372438264E-05
   0.7075838084E-04  -0.6388168824E-05  -0.1630784174E-05   0.6992653192E-04
  -0.1273207712E-04  -0.2724538903E-05   0.1420774668E-03
   0.2486278254E-03  -0.5748769663E-04  -0.8728986136E-04   0.1001732439E-03
   0.2176780735E-05  -0.3281104851E-09   0.1181433181E-03   0.5460908136E-06
  -0.7427842560E-05   0.4044295728E-03  -0.5945142692E-04  -0.1277458327E-03
   0.1146611955E-03   0.5917484952E-06  -0.5999678326E-05   0.1168214416E-02
  -0.7353741006E-04   0.1605655864E-03   0.4410664192E-04  -0.2175975437E-05
   0.1001603923E-03   0.1605987917E-07  -0.4546545402E-05   0.1149515075E-03
  -0.6810047450E-06  -0.7825542735E-04   0.3054005320E-03   0.2801963842E-04
  -0.4343416315E-05   0.1117297523E-03  -0.2605703698E-06  -0.1157307200E-03
   0.9878200182E-03
  -0.8561083944E-04   0.2751977921E-04   0.2979008017E-03   0.6768923215E-07
  -0.1604896234E-05   0.1001840206E-05  -0.7254007120E-05  -0.3878404835E-05
```



```
 0.8634208467E-04  -0.1395244864E-03  -0.7058761248E-05   0.1203872986E-02
-0.6167369200E-05  -0.3198906377E-05   0.6961197588E-04  -0.4524556972E-03
-0.7529675987E-04   0.5198875218E-02
 0.1124783442E-03  -0.2112353121E-05  -0.6089562833E-05   0.1001967380E-03
-0.1787296024E-06   0.3350382286E-10   0.1148740439E-03  -0.1799517910E-05
-0.6109018398E-05   0.1181903034E-03  -0.3415548214E-05  -0.6812730028E-05
 0.1145854875E-03  -0.2016030775E-05  -0.5890614248E-05   0.1232402710E-03
-0.5589248709E-05  -0.9954847325E-05   0.1296574876E-03
-0.4193215670E-05   0.1077823779E-03   0.1375644802E-05   0.1787338586E-06
 0.1001966512E-03  -0.1319152838E-08  -0.1311626412E-05   0.1121666053E-03
-0.1856624673E-05  -0.3095731504E-05   0.1131178353E-03  -0.6803099124E-06
-0.1532633834E-05   0.1115943847E-03  -0.1610538125E-05   0.2759695856E-06
 0.1188899040E-03  -0.4580146368E-05  -0.2854923849E-05   0.1245363622E-03
-0.5993240368E-05   0.1819706061E-06   0.4419802648E-04  -0.3115065705E-08
 0.1319210503E-06   0.1001968105E-05  -0.6119033310E-05  -0.1535295704E-05
 0.7147013388E-04  -0.8303445121E-05  -0.5207118841E-06   0.7730088391E-04
-0.6199271351E-05  -0.1291606766E-05   0.6890794222E-04  -0.1022442109E-04
-0.3636817033E-06   0.1109336307E-03  -0.1227224465E-04  -0.3721620783E-05
 0.1436095677E-03
 0.4211391522E-03  -0.1322284517E-03  -0.1863440956E-03   0.1001850612E-03
 0.9954847262E-07   0.1536831297E-07   0.1081651513E-03  -0.1248750417E-05
-0.2770257988E-05   0.3023852909E-03  -0.8485174281E-04  -0.1189168921E-03
 0.1146245826E-03  -0.1802716417E-05  -0.4417850120E-05   0.1535349576E-03
-0.2571189035E-04  -0.2844529889E-04   0.1088696417E-03  -0.1395390542E-05
-0.3199186215E-05   0.1364945478E-02
-0.1432134107E-03   0.2252005237E-03   0.7955423185E-04  -0.1007002537E-06
 0.1001968192E-03   0.7432225009E-09  -0.1312753645E-05   0.1063664290E-03
-0.5837680287E-06  -0.8736383508E-04   0.1823610498E-03   0.4845204643E-04
-0.1795798220E-05   0.1120379632E-03  -0.1546116216E-05  -0.1950023751E-04
 0.1245004665E-03   0.8926711329E-05  -0.1922793484E-05   0.1065238670E-03
-0.2101323934E-06  -0.5905316705E-03   0.5715701623E-03
-0.2037904077E-03   0.7043297173E-04   0.6305216227E-03  -0.1536756257E-05
-0.7585802227E-07   0.1001850831E-05  -0.5236995239E-05  -0.5458372760E-06
 0.3693979669E-04  -0.1333241566E-03   0.4603040548E-04   0.4114005334E-03
-0.8017249199E-05  -0.1454599414E-05   0.7062142480E-04  -0.3366601298E-04
 0.1449260104E-04   0.1226273694E-03  -0.5663218412E-05  -0.4313342938E-06
 0.3777252457E-04  -0.7948485109E-03   0.3562535433E-03   0.2097677055E-02
14
91     77X251         78X000
91     77X251         89X001
91     77X251         89X002
91     89X004         89X003
91     78X000         89X005
91     78X000         89X001
91     89X001         89X004
91     89X001         89X005
91     77X251         89X002
91     77X251         89X003
91     77X251         89X006
91     77X251         78X000
91     77X251         89X001
91     77X251         89X002
```

TEST2.DAT

BASE.DAT network data file with 0.03 m random error, 0.1 m translation along the x-axis, 10" rotation about the z-axis and 2 ppm scale change.

```
Perturbed CCS 1990 GPS Validation Survey: rand=0.03m,dx=0.1m,rotz=10",ds=2ppm
  8     77X251
 89X003         53 33 53.929779    -112 24 35.772576     669.8182     669.8182
 77X251         53 34 14.387114    -113 10 25.596190     684.9443     684.9443
 78X000         53 34 14.444884    -113 11 44.790426     670.3996     670.3996
 89X004         54  2  9.952649    -113  9 19.136469     616.9087     616.9087
 89X002         53 39 27.234024    -113 11 35.545906     619.9243     619.9243
 89X005         53 35 57.689065    -114 43 13.662151     767.8226     767.8226
 89X001         53 34  7.746384    -113  2 48.292907     715.9779     715.9779
 89X006         52 41 30.611584    -113 14 42.992664     763.7995     763.7995
 1.0
   0.1064811164E-02
  -0.4077391926E-03   0.4579996559E-03
  -0.5820234740E-03   0.2117978395E-03   0.1819417002E-02
   0.1001911334E-03   0.1074716782E-05  -0.5720789742E-08   0.1001968974E-03
  -0.1074637806E-05   0.1001879936E-03   0.7933062809E-06   0.7344502925E-19
   0.1001968974E-03
   0.1422932303E-09  -0.7931992871E-08   0.1001937567E-05   0.2158110218E-21
   0.5232666027E-22   0.1001968974E-05
   0.1098978839E-03  -0.7132286043E-06  -0.4539966315E-05   0.1001968926E-03
   0.3095428112E-07  -0.2477728917E-12   0.1304420185E-03
  -0.3212531457E-05   0.1069448950E-03   0.7980759139E-06  -0.3095427466E-07
   0.1001968900E-03   0.2284593394E-09  -0.2895809243E-05   0.1254061407E-03
  -0.4377442665E-05  -0.6338270328E-06   0.3987316157E-04   0.3183518521E-10
  -0.2284592519E-07   0.1001968948E-05  -0.1276451447E-04  -0.3402756547E-05
   0.1477747040E-03
   0.7026961690E-03  -0.2484577125E-03  -0.3769975492E-03   0.1001935881E-03
  -0.2618395872E-07  -0.8139225184E-08   0.1125869098E-03  -0.2093560479E-05
  -0.5578045264E-05   0.1366082722E-02
  -0.2600787731E-03   0.3315311130E-03   0.1390385441E-03   0.2602876457E-07
   0.1001968922E-03  -0.1921064029E-09  -0.1920726576E-05   0.1094582663E-03
  -0.8225278533E-06  -0.2276074730E-03   0.9945120795E-03
  -0.3716029587E-03   0.1298121401E-03   0.1162939357E-02   0.8139274962E-06
   0.1899856813E-07   0.1001935897E-05  -0.4313784655E-05  -0.5798555162E-06
   0.5524838920E-04  -0.6343840065E-03  -0.4994693104E-04   0.5025892127E-02
   0.1147835303E-03  -0.3982915933E-06  -0.6248255627E-05   0.1001967784E-03
   0.2735945619E-07  -0.1519685682E-08   0.1150238074E-03  -0.1845723036E-05
  -0.6518548666E-05   0.1147724983E-03  -0.1672229734E-05  -0.5302752050E-05
   0.1300400325E-03
  -0.3048932248E-05   0.1119839277E-03  -0.4902050834E-06  -0.2732889494E-07
   0.1001968917E-03   0.2017020703E-09  -0.1841544295E-05   0.1119746674E-03
  -0.1369138240E-05  -0.1851343143E-05   0.1118767353E-03  -0.1396131709E-05
  -0.3619574121E-05   0.1240096030E-03
  -0.5709759481E-05  -0.2302415768E-05   0.7044761014E-04   0.1519740671E-06
  -0.2012873336E-07   0.1001967801E-05  -0.6210461874E-05  -0.1372438264E-05
   0.7075838084E-04  -0.6388168824E-05  -0.1630784174E-05   0.6992653192E-04
  -0.1273207712E-04  -0.2724538903E-05   0.1420774668E-03
   0.2486278254E-03  -0.5748769663E-04  -0.8728986136E-04   0.1001732439E-03
   0.2176780735E-05  -0.3281104851E-09   0.1181433181E-03   0.5460908136E-06
  -0.7427842560E-05   0.4044295728E-03  -0.5945142692E-04  -0.1277458327E-03
   0.1146611955E-03   0.5917484952E-06  -0.5999678326E-05   0.1168214416E-02
  -0.7353741006E-04   0.1605655864E-03   0.4410664192E-04  -0.2175975437E-05
   0.1001603923E-03   0.1605987917E-07  -0.4546545402E-05   0.1149515075E-03
  -0.6810047450E-06  -0.7825542735E-04   0.3054005320E-03   0.2801963842E-04
  -0.4343416315E-05   0.1117297523E-03  -0.2605703698E-06  -0.1157307200E-03
   0.9878200182E-03
  -0.8561083944E-04   0.2751977921E-04   0.2979008017E-03   0.6768923215E-07
```



```
 -0.1604896234E-05  0.1001840206E-05 -0.7254007120E-05 -0.3878404835E-05
  0.8634208467E-04 -0.1395244864E-03 -0.7058761248E-05  0.1203872986E-02
 -0.6167369200E-05 -0.3198906377E-05  0.6961197588E-04 -0.4524556972E-03
 -0.7529675987E-04  0.5198875218E-02
  0.1124783442E-03 -0.2112353121E-05 -0.6089562833E-05  0.1001967380E-03
 -0.1787296024E-06  0.3350382286E-10  0.1148740439E-03 -0.1799517910E-05
 -0.6109018398E-05  0.1181903034E-03 -0.3415548214E-05 -0.6812730028E-05
  0.1145854875E-03 -0.2016030775E-05 -0.5890614248E-05  0.1232402710E-03
 -0.5589248709E-05 -0.9954847325E-05  0.1296574876E-03
 -0.4193215670E-05  0.1077823779E-03  0.1375644802E-05  0.1787338586E-06
  0.1001966512E-03 -0.1319152838E-08 -0.1311626412E-05  0.1121666053E-03
 -0.1856624673E-05 -0.3095731504E-05  0.1131178353E-03 -0.6803099124E-06
 -0.1532633834E-05  0.1115943847E-03 -0.1610538125E-05  0.2759695856E-06
  0.1188899040E-03 -0.4580146368E-05 -0.2854923849E-05  0.1245363622E-03
 -0.5993240368E-05  0.1819706061E-06  0.4419802648E-04 -0.3115065705E-08
  0.1319210503E-06  0.1001968105E-05 -0.6119033310E-05 -0.1535295704E-05
  0.7147013388E-04 -0.8303445121E-05 -0.5207118841E-06  0.7730088391E-04
 -0.6199271351E-05 -0.1291606766E-05  0.6890794222E-04 -0.1022442109E-04
 -0.3636817033E-06  0.1109336307E-03 -0.1227224465E-04 -0.3721620783E-05
  0.1436095677E-03
  0.4211391522E-03 -0.1322284517E-03 -0.1863440956E-03  0.1001850612E-03
  0.9954847262E-07  0.1536831297E-07  0.1081651513E-03 -0.1248750417E-05
 -0.2770257988E-05  0.3023852909E-03 -0.8485174281E-04 -0.1189168921E-03
  0.1146245826E-03 -0.1802716417E-05 -0.4417850120E-05  0.1535349576E-03
 -0.2571189035E-04 -0.2844529889E-04  0.1088696417E-03 -0.1395390542E-05
 -0.3199186215E-05  0.1364945478E-02
 -0.1432134107E-03  0.2252005237E-03  0.7955423185E-04 -0.1007002537E-06
  0.1001968192E-03  0.7432225009E-09 -0.1312753645E-05  0.1063664290E-03
 -0.5837680287E-06 -0.8736383508E-04  0.1823610498E-03  0.4845204643E-04
 -0.1795798220E-05  0.1120379632E-03 -0.1546116216E-05 -0.1950023751E-04
  0.1245004665E-03  0.8926711329E-05 -0.1922793484E-05  0.1065238670E-03
 -0.2101323934E-06 -0.5905316705E-03  0.5715701623E-03
 -0.2037904077E-03  0.7043297173E-04  0.6305216227E-03 -0.1536756257E-05
 -0.7585802227E-07  0.1001850831E-05 -0.5236995239E-05 -0.5458372760E-06
  0.3693979669E-04 -0.1333241566E-03  0.4603040548E-04  0.4114005334E-03
 -0.8017249199E-05 -0.1454599414E-05  0.7062142480E-04 -0.3366601298E-04
  0.1449260104E-04  0.1226273694E-03 -0.5663218412E-05 -0.4313342938E-06
  0.3777252457E-04 -0.7948485109E-03  0.3562535433E-03  0.2097677055E-02
14
91     77X251         78X000
91     77X251         89X001
91     77X251         89X002
91     89X004         89X003
91     78X000         89X005
91     78X000         89X001
91     89X001         89X004
91     89X001         89X005
91     77X251         89X002
91     77X251         89X003
91     77X251         89X006
91     77X251         78X000
91     77X251         89X001
91     77X251         89X002
```


BASE.REG

Output listing from NETREG for BASE.DAT input network data file.

```
-------------------------------------------------------
 NETREG:  Network Confidence Regions
          Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

Input Network Data File : base.dat
CCS 1990 GPS Validation Survey

Ellipsoid Parameters:
  Major semi-axis    =    6378137.000
  Inverse Flattening = 298.2572221010

Specified Order of Accuracy : 1st

Statistical Confidence Level : 95.0%
  1-d Scale Factor = 1.960
  2-d Scale Factor = 2.448
  3-d Scale Factor = 2.795


------------------------------------------------------------------------
 Absolute Confidence Regions -- 3D

                                             Ellipsoid Axes
 Station       Dist. from     Specs    Length     Az   Inc    Pass/Fail
               Fixed  (m)      (m)       (m)    (deg) (deg)
------------------------------------------------------------------------

 89X003         50615.562     1.161     0.132    157    57      Pass
                                        0.083    329    33
                                        0.044     61     3

 77X251             0.000     0.005     0.028     45     0      Fail
                                        0.028    135     0
                                        0.003    194    90

 78X000          1457.671     0.038     0.035    187    62      Pass
                                        0.032    127   -15
                                        0.031     44    23

 89X004         51822.883     1.189     0.200    181    80      Pass
                                        0.104    329     8
                                        0.082     60     5

 89X002          9758.268     0.228     0.034    182    58      Pass
                                        0.032    124   -19
                                        0.030     44    25

 89X005        102489.258     2.346     0.203    188    84      Pass
                                        0.097    329     5
                                        0.084     59     4

 89X001          8419.141     0.197     0.034    188    60      Pass
                                        0.032    126   -15
                                        0.030     44    25

 89X006         97930.463     2.242     0.147    154    52      Pass
```

			0.088	328	38	
			0.045	60	3	

Absolute Confidence Regions -- Horizontal and Vertical Projections

Station	Dist. from Fixed (m)	Specs (m)	Horizontal Length (m)	Horizontal Az (deg)	Vertical Length (m)	Pass/Fail
89X003	50615.103	1.017	0.087	333	0.084	Pass
			0.039	63		
77X251	0.000	0.004	0.025	45	0.002	Fail
			0.025	135		
78X000	1457.597	0.033	0.028	336	0.024	Pass
			0.027	66		
89X004	51822.135	1.041	0.094	335	0.139	Pass
			0.073	65		
89X002	9757.998	0.199	0.028	335	0.023	Pass
			0.027	65		
89X005	102486.596	2.054	0.086	334	0.141	Pass
			0.075	64		
89X001	8419.103	0.172	0.028	336	0.023	Pass
			0.027	66		
89X006	97928.150	1.963	0.100	332	0.090	Pass
			0.039	62		

Relative Confidence Regions -- 3D

From Station	To Station	Dist. from Fixed (m)	Specs (m)	Ellipsoid Axes Length (m)	Az (deg)	Inc (deg)	Pass/Fail
89X003	77X251	50615.562	1.161	0.131	157	59	Pass
				0.079	329	31	
				0.034	61	3	
89X003	78X000	52073.063	1.194	0.133	157	60	Pass
				0.080	330	30	
				0.035	61	3	
89X003	89X004	71849.745	1.646	0.189	190	82	Pass
				0.090	331	6	
				0.075	61	5	
89X003	89X002	52859.809	1.212	0.131	157	59	Pass
				0.079	330	31	
				0.034	61	3	
89X003	89X005	153081.964	3.502	0.227	172	80	Pass
				0.118	330	10	
				0.084	61	4	

89X003	89X001	42198.042	0.969	0.132	157	60	Pass
				0.080	329	30	
				0.035	61	3	
89X003	89X006	112119.685	2.566	0.164	155	54	Pass
				0.096	329	36	
				0.039	61	3	
77X251	78X000	1457.671	0.038	0.034	193	84	Pass
				0.015	330	5	
				0.013	60	4	
77X251	89X004	51822.883	1.189	0.200	181	81	Pass
				0.101	330	8	
				0.077	60	5	
77X251	89X002	9758.268	0.228	0.033	190	83	Pass
				0.015	330	5	
				0.013	61	4	
77X251	89X005	102489.258	2.346	0.203	187	84	Pass
				0.092	329	5	
				0.080	59	4	
77X251	89X001	8419.141	0.197	0.034	196	84	Pass
				0.015	330	4	
				0.013	61	4	
77X251	89X006	97930.463	2.242	0.146	154	53	Pass
				0.085	329	37	
				0.035	60	2	
78X000	89X004	51875.346	1.190	0.201	181	81	Pass
				0.101	330	8	
				0.077	60	5	
78X000	89X002	9672.821	0.226	0.034	193	84	Pass
				0.016	330	5	
				0.014	60	4	
78X000	89X005	101032.817	2.313	0.202	188	84	Pass
				0.092	329	5	
				0.080	59	4	
78X000	89X001	9876.476	0.230	0.034	195	84	Pass
				0.015	330	4	
				0.014	60	4	
78X000	89X006	97871.183	2.241	0.148	154	54	Pass
				0.087	329	36	
				0.036	60	2	
89X004	89X002	42209.225	0.969	0.200	181	81	Pass
				0.101	330	8	
				0.077	60	5	
89X004	89X005	113977.127	2.609	0.249	188	82	Pass
				0.117	329	6	
				0.098	60	5	
89X004	89X001	52503.764	1.204	0.200	181	81	Pass
				0.100	330	8	
				0.077	60	5	

89X004	89X006	149739.308	3.426	0.228	165	74	Pass
				0.130	329	15	
				0.081	60	4	
89X002	89X005	101255.916	2.318	0.203	188	84	Pass
				0.092	329	5	
				0.080	59	4	
89X002	89X001	13840.633	0.321	0.034	194	84	Pass
				0.016	330	5	
				0.014	60	4	
89X002	89X006	107542.076	2.462	0.147	154	53	Pass
				0.085	329	37	
				0.035	60	2	
89X005	89X001	110906.996	2.539	0.201	188	84	Pass
				0.092	329	5	
				0.079	59	4	
89X005	89X006	141229.019	3.231	0.240	164	76	Pass
				0.134	329	14	
				0.086	60	3	
89X001	89X006	98508.771	2.255	0.148	154	54	Pass
				0.087	329	36	
				0.036	60	2	

Relative Confidence Regions -- Horizontal and Vertical Projections

From Station	To Station	Dist. from Fixed (m)	Specs (m)	Horizontal Length (m)	Horizontal Az (deg)	Vertical Length (m)	Pass/Fail
89X003	77X251	50615.223	1.017	0.084	333	0.084	Pass
				0.030	63		
89X003	78X000	52072.634	1.046	0.084	333	0.085	Pass
				0.031	63		
89X003	89X004	71848.290	1.441	0.080	336	0.132	Pass
				0.066	66		
89X003	89X002	52859.127	1.062	0.084	333	0.084	Pass
				0.030	63		
89X003	89X005	153072.133	3.066	0.107	334	0.157	Pass
				0.075	64		
89X003	89X001	42197.939	0.848	0.084	333	0.085	Pass
				0.031	63		
89X003	89X006	112116.145	2.247	0.108	332	0.101	Pass
				0.035	62		
77X251	78X000	1457.597	0.033	0.014	336	0.024	Pass
				0.012	66		
77X251	89X004	51822.135	1.041	0.091	335	0.139	Pass
				0.069	65		

77X251	89X002	9757.998	0.199	0.014 0.012	335 65	0.023	Pass
77X251	89X005	102486.596	2.054	0.082 0.071	334 64	0.141	Pass
77X251	89X001	8419.103	0.172	0.014 0.012	336 66	0.023	Pass
77X251	89X006	97928.150	1.963	0.097 0.031	332 62	0.090	Pass
78X000	89X004	51874.672	1.042	0.091 0.069	335 65	0.139	Pass
78X000	89X002	9672.648	0.198	0.014 0.012	336 66	0.024	Pass
78X000	89X005	101030.385	2.025	0.082 0.070	334 64	0.141	Pass
78X000	89X001	9876.403	0.202	0.014 0.012	336 66	0.024	Pass
78X000	89X006	97868.974	1.962	0.098 0.032	332 62	0.091	Pass
89X004	89X002	42209.004	0.848	0.091 0.069	335 65	0.139	Pass
89X004	89X005	113973.840	2.284	0.104 0.087	335 65	0.173	Pass
89X004	89X001	52503.633	1.054	0.090 0.069	335 65	0.139	Pass
89X004	89X006	149730.642	3.000	0.121 0.072	333 63	0.156	Pass
89X002	89X005	101253.804	2.030	0.082 0.071	334 64	0.141	Pass
89X002	89X001	13840.395	0.281	0.014 0.012	336 66	0.024	Pass
89X002	89X006	107539.370	2.155	0.097 0.031	332 62	0.090	Pass
89X005	89X001	110902.362	2.223	0.081 0.070	334 64	0.140	Pass
89X005	89X006	141220.337	2.829	0.124 0.076	332 62	0.165	Pass
89X001	89X006	98506.191	1.975	0.098 0.032	332 62	0.091	Pass

TEST1.DIF

Output listing from NETDIF for BASE.DAT & TEST1.DAT input network data files.

```
-------------------------------------------------------
 NETDIF:  Network Coordinate Difference Analysis
           Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

1st (base) Network : base.dat
CCS 1990 GPS Validation Survey
Fixed Station: 77X251

2nd (test) Network : test1.dat
Perturbed CCS 1990 GPS Validation Survey: 0.03m random error
Fixed Station: 77X251

Ellipsoid Parameters:
  Major Semi-Axis (m) =    6378137.000
  Inverse Flattening  = 298.2572221010

Specified Order of Accuracy : 1st

Statistical Confidence Level: 95.0%


-------------------------------------------------------------------------
 Common Stations

 Station      Network         Latitude          Longitude     Ell.Height
               File           (D M S)            (D M S)         (m)
-------------------------------------------------------------------------

 89X003       base.dat     53 33 53.84837   -112 24 35.78287    669.794
              test1.dat    53 33 53.84725   -112 24 35.78052    669.818

 77X251       base.dat     53 34 14.38388   -113 10 25.59619    684.944
              test1.dat    53 34 14.38388   -113 10 25.59619    684.944

 78X000       base.dat     53 34 14.44215   -113 11 44.79469    670.374
              test1.dat    53 34 14.44394   -113 11 44.79026    670.400

 89X004       base.dat     54  2  9.94409   -113  9 18.99992    616.917
              test1.dat    54  2  9.94414   -113  9 18.99861    616.908

 89X002       base.dat     53 39 27.23137   -113 11 35.51892    619.886
              test1.dat    53 39 27.23218   -113 11 35.52023    619.924

 89X005       base.dat     53 35 57.84741   -114 43 13.64524    767.804
              test1.dat    53 35 57.84636   -114 43 13.64540    767.821

 89X001       base.dat     53 34  7.72900   -113  2 48.29376    715.984
              test1.dat    53 34  7.72997   -113  2 48.29439    715.978

 89X006       base.dat     52 41 30.62300   -113 14 43.24432    763.832
              test1.dat    52 41 30.62211   -113 14 43.24461    763.799


----------------------------------------------------------------
 Coordinate Discrepancies (Test - Base)
```

Station	dy (N) +/-std (m)	dy (E) +/-std (m)	dz (V) +/-std (m)	2D Vector (m)	3D Vector (m)
89X003	-0.035 0.046	0.043 0.030	0.023 0.060	0.055	0.060
77X251	0.000 0.014	0.000 0.014	0.000 0.001	0.000	0.000
78X000	0.055 0.016	0.082 0.016	0.026 0.017	0.098	0.102
89X004	0.002 0.052	0.024 0.045	-0.009 0.100	0.024	0.026
89X002	0.025 0.016	-0.024 0.016	0.038 0.017	0.035	0.052
89X005	-0.032 0.048	-0.003 0.044	0.017 0.102	0.032	0.037
89X001	0.030 0.016	-0.012 0.016	-0.006 0.017	0.032	0.032
89X006	-0.028 0.052	-0.005 0.034	-0.033 0.065	0.028	0.043

Mean and Standard Deviation of Coordinate Discrepancies

	dx (m)	dy (m)	dz (m)	2D (m)	3D (m)	Length of Vector of Means (m)
Mean	0.002	0.013	0.007	0.038	0.044	0.015
St.Dev	0.033	0.035	0.023	0.029	0.030	

Maximum Coordinate Discrepancies

Station	dx (m)	dy (m)	dz (m)	2D (m)	3D (m)
78X000	0.055				
78X000		0.082			
89X002			0.038		
78X000				0.098	
78X000					0.102

Comparison of Coordinate Discrepancies with Specifications

Station	Dist. From Fixed Sta. (m)	2D Error (m)	2D Specs (m)	Pass/Fail	3D Error (m)	3D Specs (m)	Pass/Fail
89X003	50615.562	0.055	1.016	Pass	0.060	1.161	Pass
77X251	0.000	0.000	0.004	Pass	0.000	0.005	Pass

78X000	1457.671	0.098	0.033	Fail	0.102	0.038	Fail
89X004	51822.883	0.024	1.040	Pass	0.026	1.188	Pass
89X002	9758.268	0.035	0.199	Pass	0.052	0.227	Pass
89X005	102489.258	0.032	2.054	Pass	0.037	2.346	Pass
89X001	8419.141	0.032	0.172	Pass	0.032	0.197	Pass
89X006	97930.463	0.028	1.963	Pass	0.043	2.242	Pass

Chi-Square Tests of Station Coordinate Discrepancies

Station	Computed	Out-of-Context Test		In-Context Test	
	Chi-Square	Chi-Square	Pass/Fail	Chi-Square	Pass/Fail
89X003	2.066	7.815	Pass	12.423	Pass
77X251	0.000	7.815	Pass	12.423	Pass
78X000	42.799	7.815	Fail	12.423	Fail
89X004	0.309	7.815	Pass	12.423	Pass
89X002	10.390	7.815	Fail	12.423	Pass
89X005	0.469	7.815	Pass	12.423	Pass
89X001	3.938	7.815	Pass	12.423	Pass
89X006	1.473	7.815	Pass	12.423	Pass

Chi-Square Tests of Coordinate Discrepancy Sets

Element	Computed	Out-of-Context Test		In-Context Test	
Tested	Chi-Square	Chi-Square	Pass/Fail	Chi-Square	Pass/Fail
dx (lat)	54.391	15.491	Fail	18.693	Fail
dy (long)	269.644	15.491	Fail	18.693	Fail
dz (ht)	9.806	15.491	Pass	18.693	Pass
2D vector	341.895	26.289	Fail	27.806	Fail
3D vector	364.804	36.411	Fail	36.411	Fail

TEST2.TRN

Output listing from NETRAN for BASE.DAT & TEST2.DAT input network data files.

```
-------------------------------------------------------
 NETRAN:  Network Helmert (Datum) Tranformation
          Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

1st (base) Network : base.dat
CCS 1990 GPS Validation Survey
Fixed Station: 77X251

2nd (test) Network : test2.dat
Perturbed CCS 1990 GPS Validation Survey: rand=0.03m,dx=0.1m,rotz=10",ds=2ppm
Fixed Station: 77X251

Transformed 2nd Network :

Ellipsoid Parameters:
  Major Semi-Axis (m) =    6378137.00000000
  Inverse Flattening  =    298.257222101000

All Parameters Free (Unconstrained)


-------------------------------------------------------------------------
 Common Stations

 Station      Network         Latitude          Longitude     Ell.Height
               File           (D M S)           (D M S)          (m)
-------------------------------------------------------------------------

 89X003       base.dat     53 33 53.84837   -112 24 35.78287    669.794
              test2.dat    53 33 53.92978   -112 24 35.77258    669.818

 77X251       base.dat     53 34 14.38388   -113 10 25.59619    684.944
              test2.dat    53 34 14.38711   -113 10 25.59619    684.944

 78X000       base.dat     53 34 14.44215   -113 11 44.79469    670.374
              test2.dat    53 34 14.44488   -113 11 44.79043    670.400

 89X004       base.dat     54  2  9.94409   -113  9 18.99992    616.917
              test2.dat    54  2  9.95265   -113  9 19.13647    616.909

 89X002       base.dat     53 39 27.23137   -113 11 35.51892    619.886
              test2.dat    53 39 27.23402   -113 11 35.54591    619.924

 89X005       base.dat     53 35 57.84741   -114 43 13.64524    767.804
              test2.dat    53 35 57.68907   -114 43 13.66215    767.823

 89X001       base.dat     53 34  7.72900   -113  2 48.29376    715.984
              test2.dat    53 34  7.74638   -113  2 48.29291    715.978

 89X006       base.dat     52 41 30.62300   -113 14 43.24432    763.832
              test2.dat    52 41 30.61158   -113 14 42.99266    763.799


-------------------------------------------------------------
Variance Factor and Chi-Square Test of Significance
-------------------------------------------------------------
```

```
Variance Factor =    21.03

95% Confidence Interval:     0.44  <       21.03  <     1.78

***** Test Failed *****
Multiplied Covariance Matrix by Variance Factor


-------------------------------------------------------------
Final Transformation Parameters (Test to Basis Network)
-------------------------------------------------------------

Coordinate System Origin at Fixed Station 77X251
Number of Iterations =          2

Rotation about x =     -0.1681 +/-      0.5683 (arcsec)
Rotation about y =     -0.1671 +/-      0.4595 (arcsec)
Rotation about z =    -10.0616 +/-      0.1546 (arcsec)
Translation in x =     -0.1002 +/-      0.0649 (metres)
Translation in y =      0.0000 +/-      0.0649 (metres)
Translation in z =      0.0000 +/-      0.0065 (metres)
Scale error      =     -2.1375 +/-      0.7768 (ppm)


-------------------------------------------------------------
Covariance Matrix of Parameters
-------------------------------------------------------------

    0.32292E+00    0.48843E-12    0.35215E-12    0.73044E-10   -0.38289E-09
   -0.97799E-13    0.21570E-12
    0.48843E-12    0.21117E+00   -0.73130E-13    0.32747E-09    0.96977E-10
   -0.44332E-12   -0.34897E-12
    0.35215E-12   -0.73130E-13    0.23898E-01    0.19465E-09   -0.26839E-09
   -0.86117E-14    0.18911E-12
    0.73044E-10    0.32747E-09    0.19465E-09    0.42139E-02   -0.22274E-07
   -0.17332E-08    0.55820E-09
   -0.38289E-09    0.96977E-10   -0.26839E-09   -0.22274E-07    0.42138E-02
    0.16760E-08   -0.21037E-09
   -0.97799E-13   -0.44332E-12   -0.86117E-14   -0.17332E-08    0.16760E-08
    0.42141E-04   -0.65632E-11
    0.21570E-12   -0.34897E-12    0.18911E-12    0.55820E-09   -0.21037E-09
   -0.65632E-11    0.60340E+00


-------------------------------------------------------------
Correlation Matrix of Parameters
-------------------------------------------------------------

    0.10000E+01    0.18704E-11    0.40086E-11    0.19801E-08   -0.10380E-07
   -0.26511E-10    0.48866E-12
    0.18704E-11    0.10000E+01   -0.10294E-11    0.10978E-07    0.32510E-08
   -0.14861E-09   -0.97762E-12
    0.40086E-11   -0.10294E-11    0.10000E+01    0.19397E-07   -0.26745E-07
   -0.85813E-11    0.15748E-11
    0.19801E-08    0.10978E-07    0.19397E-07    0.10000E+01   -0.52860E-05
   -0.41129E-05    0.11070E-07
   -0.10380E-07    0.32510E-08   -0.26745E-07   -0.52860E-05    0.10000E+01
    0.39773E-05   -0.41720E-08
   -0.26511E-10   -0.14861E-09   -0.85813E-11   -0.41129E-05    0.39773E-05
    0.10000E+01   -0.13016E-08
    0.48866E-12   -0.97762E-12    0.15748E-11    0.11070E-07   -0.41720E-08
   -0.13016E-08    0.10000E+01
```

Coordinate Differences After Helmert (Datum) Transformation
(Transformed - Base Network)

Station Name	Delta x (m)	Delta y (m)	Delta z (m)	Delta r (m)
89X003	-0.0495	0.0370	0.0646	0.0894
77X251	-0.0002	0.0000	0.0000	0.0002
78X000	0.0554	0.0817	0.0245	0.1017
89X004	-0.0063	0.0394	-0.0504	0.0643
89X002	0.0242	-0.0209	0.0294	0.0435
89X005	-0.0031	0.0120	-0.0698	0.0708
89X001	0.0271	-0.0128	0.0014	0.0300
89X006	-0.0131	-0.0335	0.0420	0.0553

Chi-Square Test of Signficance of Coordinate Misclosures

Station Name	Computed Chi-Square	95% Chi-Square	Pass/Fail
89X003	3.692	7.815	Pass
77X251	0.001	7.815	Pass
78X000	315.209	7.815	Fail ***
89X004	1.350	7.815	Pass
89X002	32.226	7.815	Fail ***
89X005	0.606	7.815	Pass
89X001	22.424	7.815	Fail ***
89X006	5.055	7.815	Pass

TEST2X.TRN

Output listing from NETRAN for BASE.DAT & TEST2.DAT input network data files with translations in y,z and rotations about x,y and scale change constrained to zero.

```
-------------------------------------------------------
 NETRAN:  Network Helmert (Datum) Tranformation
          Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

1st (base) Network : base.dat
CCS 1990 GPS Validation Survey
Fixed Station: 77X251

2nd (test) Network : test2.dat
Perturbed CCS 1990 GPS Validation Survey: rand=0.03m,dx=0.1m,rotz=10",ds=2ppm
Fixed Station: 77X251

Transformed 2nd Network : test2x.dat

Ellipsoid Parameters:
  Major Semi-Axis (m) =    6378137.00000000
  Inverse Flattening  =    298.257222101000

Parameters Constrained
A Priori Values and Standard Deviations:
  Rotation about x (N) :     0.0000 +/-   0.1000E-32 (arcsec)
  Rotation about y (E) :     0.0000 +/-   0.1000E-32 (arcsec)
  Rotation about z (UP):   -10.0000 +/-   0.1000E+34 (arcsec)
  Translation in x (N) :    -0.1000 +/-   0.1000E+34 (metres)
  Translation in y (E) :     0.0000 +/-   0.1000E-32 (metres)
  Translation in z (UP):     0.0000 +/-   0.1000E-32 (metres)
  Scale Error          :    -2.0000 +/-   0.1000E+34 (ppm)


-------------------------------------------------------------------------
 Common Stations

 Station      Network         Latitude          Longitude     Ell.Height
               File           (D M S)            (D M S)         (m)
-------------------------------------------------------------------------

 89X003       base.dat     53 33 53.84837   -112 24 35.78287    669.794
              test2.dat    53 33 53.92978   -112 24 35.77258    669.818

 77X251       base.dat     53 34 14.38388   -113 10 25.59619    684.944
              test2.dat    53 34 14.38711   -113 10 25.59619    684.944

 78X000       base.dat     53 34 14.44215   -113 11 44.79469    670.374
              test2.dat    53 34 14.44488   -113 11 44.79043    670.400

 89X004       base.dat     54  2  9.94409   -113  9 18.99992    616.917
              test2.dat    54  2  9.95265   -113  9 19.13647    616.909

 89X002       base.dat     53 39 27.23137   -113 11 35.51892    619.886
              test2.dat    53 39 27.23402   -113 11 35.54591    619.924

 89X005       base.dat     53 35 57.84741   -114 43 13.64524    767.804
              test2.dat    53 35 57.68907   -114 43 13.66215    767.823

 89X001       base.dat     53 34  7.72900   -113  2 48.29376    715.984
```

```
             test2.dat    53 34  7.74638   -113  2 48.29291    715.978

 89X006      base.dat     52 41 30.62300   -113 14 43.24432    763.832
             test2.dat    52 41 30.61158   -113 14 42.99266    763.799


------------------------------------------------------------
Variance Factor and Chi-Square Test of Significance
------------------------------------------------------------

Variance Factor =    21.28

95% Confidence Interval:     0.44  <       21.28  <     1.78

***** Test Failed *****
Multiplied Covariance Matrix by Variance Factor


------------------------------------------------------------
Final Transformation Parameters (Test to Basis Network)
------------------------------------------------------------

Coordinate System Origin at Fixed Station 77X251
Number of Iterations =          2

Rotation about x =      0.0000 +/-      0.0000 (arcsec)
Rotation about y =      0.0000 +/-      0.0000 (arcsec)
Rotation about z =    -10.0568 +/-      0.1530 (arcsec)
Translation in x =     -0.1001 +/-      0.0653 (metres)
Translation in y =      0.0000 +/-      0.0000 (metres)
Translation in z =      0.0000 +/-      0.0000 (metres)
Scale error      =     -2.1700 +/-      0.7599 (ppm)


------------------------------------------------------------
Covariance Matrix of Parameters
------------------------------------------------------------

    0.21281E-64    0.32260-140    0.23831E-76    0.27071E-74   -0.12989-135
   -0.17872-137    0.16582E-76
    0.32260-140    0.21281E-64   -0.97145E-77    0.32735E-73    0.61555-136
   -0.22114-136   -0.36800E-76
    0.23831E-76   -0.97145E-77    0.23400E-01    0.19990E-09   -0.12538E-71
   -0.62530E-74    0.17411E-12
    0.27071E-74    0.32735E-73    0.19990E-09    0.42644E-02   -0.13408E-69
   -0.70508E-71    0.58682E-09
   -0.12989-135    0.61555-136   -0.12538E-71   -0.13408E-69    0.21281E-64
   -0.45644-133   -0.96231E-72
   -0.17872-137   -0.22114-136   -0.62530E-74   -0.70508E-71   -0.45644-133
    0.21281E-64   -0.33291E-71
    0.16582E-76   -0.36800E-76    0.17411E-12    0.58682E-09   -0.96231E-72
   -0.33291E-71    0.57741E+00


------------------------------------------------------------
Correlation Matrix of Parameters
------------------------------------------------------------

    0.10000E+01    0.15159E-75    0.33770E-43    0.89863E-41   -0.61035E-71
   -0.83981E-73    0.47304E-44
    0.15159E-75    0.10000E+01   -0.13766E-43    0.10866E-39    0.28925E-71
   -0.10391E-71   -0.10498E-43
    0.33770E-43   -0.13766E-43    0.10000E+01    0.20011E-07   -0.17768E-38
   -0.88610E-41    0.14978E-11
```

```
  0.89863E-41   0.10866E-39   0.20011E-07   0.10000E+01  -0.44508E-36
 -0.23405E-37   0.11826E-07
 -0.61035E-71   0.28925E-71  -0.17768E-38  -0.44508E-36   0.10000E+01
 -0.21448E-68  -0.27452E-39
 -0.83981E-73  -0.10391E-71  -0.88610E-41  -0.23405E-37  -0.21448E-68
  0.10000E+01  -0.94971E-39
  0.47304E-44  -0.10498E-43   0.14978E-11   0.11826E-07  -0.27452E-39
 -0.94971E-39   0.10000E+01
```

Coordinate Differences After Helmert (Datum) Transformation
(Transformed - Base Network)

Station Name	Delta x (m)	Delta y (m)	Delta z (m)	Delta r (m)
89X003	-0.0481	0.0352	0.0230	0.0639
77X251	-0.0001	0.0000	0.0000	0.0001
78X000	0.0554	0.0818	0.0256	0.1021
89X004	-0.0077	0.0380	-0.0094	0.0399
89X002	0.0239	-0.0211	0.0383	0.0499
89X005	-0.0049	0.0147	0.0172	0.0231
89X001	0.0274	-0.0131	-0.0057	0.0308
89X006	-0.0094	-0.0316	-0.0332	0.0468

Chi-Square Test of Signficance of Coordinate Misclosures

Station Name	Computed Chi-Square	95% Chi-Square	Pass/Fail
89X003	2.760	7.815	Pass
77X251	0.001	7.815	Pass
78X000	316.414	7.815	Fail ***
89X004	1.027	7.815	Pass
89X002	36.181	7.815	Fail ***
89X005	0.167	7.815	Pass
89X001	22.353	7.815	Fail ***
89X006	4.491	7.815	Pass

TEST2X.DAT

Output transformed TEST2.DAT from NETRAN for BASE.DAT & TEST2.DAT input network files with translations in y,z and rotations about x,y and scale change constrained to zero.

```
Perturbed CCS 1990 GPS Validation Survey: rand=0.03m,dx=0.1m,rotz=10",ds=2ppm
          8  77X251
 89X003       53 33 53.84680   -112 24 35.78099    669.818    669.818
 77X251       53 34 14.38388   -113 10 25.59619    684.944    684.944
 78X000       53 34 14.44394   -113 11 44.79025    670.400    670.400
 89X004       54  2  9.94385   -113  9 18.99784    616.908    616.908
 89X002       53 39 27.23214   -113 11 35.52007    619.924    619.924
 89X005       53 35 57.84726   -114 43 13.64443    767.821    767.821
 89X001       53 34  7.72989   -113  2 48.29447    715.978    715.978
 89X006       52 41 30.62268   -113 14 43.24600    763.799    763.799
    1.00000
   0.1064811164E-02
  -0.4077391926E-03   0.4579996559E-03
  -0.5820234740E-03   0.2117978395E-03   0.1819417002E-02
   0.1001911334E-03   0.1074716782E-05  -0.5720789742E-08   0.1001968974E-03
  -0.1074637806E-05   0.1001879936E-03   0.7933062809E-06   0.9548912545E-19
   0.1001968974E-03
   0.1422932303E-09  -0.7931992871E-08   0.1001937567E-05   0.1925991909E-21
   0.3953847219E-22   0.1001968974E-05
   0.1098978839E-03  -0.7132286043E-06  -0.4539966315E-05   0.1001968926E-03
   0.3095428112E-07  -0.2477728917E-12   0.1304420185E-03
  -0.3212531457E-05   0.1069448950E-03   0.7980759139E-06  -0.3095427466E-07
   0.1001968900E-03   0.2284593394E-09  -0.2895809243E-05   0.1254061407E-03
  -0.4377442665E-05  -0.6338270328E-06   0.3987316157E-04   0.3183518521E-10
  -0.2284592519E-07   0.1001968948E-05  -0.1276451447E-04  -0.3402756547E-05
   0.1477747040E-03
   0.7026961690E-03  -0.2484577125E-03  -0.3769975492E-03   0.1001935881E-03
  -0.2618395872E-07  -0.8139225184E-08   0.1125869098E-03  -0.2093560479E-05
  -0.5578045264E-05   0.1366082722E-02
  -0.2600787731E-03   0.3315311130E-03   0.1390385441E-03   0.2602876457E-07
   0.1001968922E-03  -0.1921064029E-09  -0.1920726576E-05   0.1094582663E-03
  -0.8225278533E-06  -0.2276074730E-03   0.9945120795E-03
  -0.3716029587E-03   0.1298121401E-03   0.1162939357E-02   0.8139274962E-06
   0.1899856813E-07   0.1001935897E-05  -0.4313784655E-05  -0.5798555162E-06
   0.5524838920E-04  -0.6343840065E-03  -0.4994693104E-04   0.5025892127E-02
   0.1147835303E-03  -0.3982915933E-06  -0.6248255627E-05   0.1001967784E-03
   0.2735945619E-07  -0.1519685682E-08   0.1150238074E-03  -0.1845723036E-05
  -0.6518548666E-05   0.1147724983E-03  -0.1672229734E-05  -0.5302752050E-05
   0.1300400325E-03
  -0.3048932248E-05   0.1119839277E-03  -0.4902050834E-06  -0.2732889494E-07
   0.1001968917E-03   0.2017020703E-09  -0.1841544295E-05   0.1119746674E-03
  -0.1369138240E-05  -0.1851343143E-05   0.1118767353E-03  -0.1396131709E-05
  -0.3619574121E-05   0.1240096030E-03
  -0.5709759481E-05  -0.2302415768E-05   0.7044761014E-04   0.1519740671E-06
  -0.2012873336E-07   0.1001967801E-05  -0.6210461874E-05  -0.1372438264E-05
   0.7075838084E-04  -0.6388168824E-05  -0.1630784174E-05   0.6992653192E-04
  -0.1273207712E-04  -0.2724538903E-05   0.1420774668E-03
   0.2486278254E-03  -0.5748769663E-04  -0.8728986136E-04   0.1001732439E-03
   0.2176780735E-05  -0.3281104851E-09   0.1181433181E-03   0.5460908136E-06
  -0.7427842560E-05   0.4044295728E-03  -0.5945142692E-04  -0.1277458327E-03
   0.1146611955E-03   0.5917484952E-06  -0.5999678326E-05   0.1168214416E-02
  -0.7353741006E-04   0.1605655864E-03   0.4410664192E-04  -0.2175975437E-05
   0.1001603923E-03   0.1605987917E-07  -0.4546545402E-05   0.1149515075E-03
  -0.6810047450E-06  -0.7825542735E-04   0.3054005320E-03   0.2801963842E-04
  -0.4343416315E-05   0.1117297523E-03  -0.2605703698E-06  -0.1157307200E-03
   0.9878200182E-03
```



```
 -0.8561083944E-04   0.2751977921E-04   0.2979008017E-03   0.6768923215E-07
 -0.1604896234E-05   0.1001840206E-05  -0.7254007120E-05  -0.3878404835E-05
  0.8634208467E-04  -0.1395244864E-03  -0.7058761248E-05   0.1203872986E-02
 -0.6167369200E-05  -0.3198906377E-05   0.6961197588E-04  -0.4524556972E-03
 -0.7529675987E-04   0.5198875218E-02
  0.1124783442E-03  -0.2112353121E-05  -0.6089562833E-05   0.1001967380E-03
 -0.1787296024E-06   0.3350382286E-10   0.1148740439E-03  -0.1799517910E-05
 -0.6109018398E-05   0.1181903034E-03  -0.3415548214E-05  -0.6812730028E-05
  0.1145854875E-03  -0.2016030775E-05  -0.5890614248E-05   0.1232402710E-03
 -0.5589248709E-05  -0.9954847325E-05   0.1296574876E-03
 -0.4193215670E-05   0.1077823779E-03   0.1375644802E-05   0.1787338586E-06
  0.1001966512E-03  -0.1319152838E-08  -0.1311626412E-05   0.1121666053E-03
 -0.1856624673E-05  -0.3095731504E-05   0.1131178353E-03  -0.6803099124E-06
 -0.1532633834E-05   0.1115943847E-03  -0.1610538125E-05   0.2759695856E-06
  0.1188899040E-03  -0.4580146368E-05  -0.2854923849E-05   0.1245363622E-03
 -0.5993240368E-05   0.1819706061E-06   0.4419802648E-04  -0.3115065705E-08
  0.1319210503E-06   0.1001968105E-05  -0.6119033310E-05  -0.1535295704E-05
  0.7147013388E-04  -0.8303445121E-05  -0.5207118841E-06   0.7730088391E-04
 -0.6199271351E-05  -0.1291606766E-05   0.6890794222E-04  -0.1022442109E-04
 -0.3636817033E-06   0.1109336307E-03  -0.1227224465E-04  -0.3721620783E-05
  0.1436095677E-03
  0.4211391522E-03  -0.1322284517E-03  -0.1863440956E-03   0.1001850612E-03
  0.9954847262E-07   0.1536831297E-07   0.1081651513E-03  -0.1248750417E-05
 -0.2770257988E-05   0.3023852909E-03  -0.8485174281E-04  -0.1189168921E-03
  0.1146245826E-03  -0.1802716417E-05  -0.4417850120E-05   0.1535349576E-03
 -0.2571189035E-04  -0.2844529889E-04   0.1088696417E-03  -0.1395390542E-05
 -0.3199186215E-05   0.1364945478E-02
 -0.1432134107E-03   0.2252005237E-03   0.7955423185E-04  -0.1007002537E-06
  0.1001968192E-03   0.7432225009E-09  -0.1312753645E-05   0.1063664290E-03
 -0.5837680287E-06  -0.8736383508E-04   0.1823610498E-03   0.4845204643E-04
 -0.1795798220E-05   0.1120379632E-03  -0.1546116216E-05  -0.1950023751E-04
  0.1245004665E-03   0.8926711329E-05  -0.1922793484E-05   0.1065238670E-03
 -0.2101323934E-06  -0.5905316705E-03   0.5715701623E-03
 -0.2037904077E-03   0.7043297173E-04   0.6305216227E-03  -0.1536756257E-05
 -0.7585802227E-07   0.1001850831E-05  -0.5236995239E-05  -0.5458372760E-06
  0.3693979669E-04  -0.1333241566E-03   0.4603040548E-04   0.4114005334E-03
 -0.8017249199E-05  -0.1454599414E-05   0.7062142480E-04  -0.3366601298E-04
  0.1449260104E-04   0.1226273694E-03  -0.5663218412E-05  -0.4313342938E-06
  0.3777252457E-04  -0.7948485109E-03   0.3562535433E-03   0.2097677055E-02
        14
91     77X251         78X000
91     77X251         89X001
91     77X251         89X002
91     89X004         89X003
91     78X000         89X005
91     78X000         89X001
91     89X001         89X004
91     89X001         89X005
91     77X251         89X002
91     77X251         89X003
91     77X251         89X006
91     77X251         78X000
91     77X251         89X001
91     77X251         89X002
```

TEST1.STR

Output listing from NETSTR for BASE.DAT & TEST1.DAT input network data files.

```
 -------------------------------------------------------
  NETSTR:  Network Strain Analysis
           Version 1.0 (20 Apr 90)
  Copyright (c) 1990 Geodetic Research Services Limited
 -------------------------------------------------------

 Piece-Wise Linear Approximation -- Connected Stations

 1st (base) Network : base.dat
 CCS 1990 GPS Validation Survey
 Fixed Station: 77X251

 2nd (test) Network : test1.dat
 Perturbed CCS 1990 GPS Validation Survey: 0.03m random error
 Fixed Station: 77X251

 Output Plot Data File : test1.plt

 Ellipsoid Parameters:
   Major Semi-Axis (m) =    6378137.000
   Inverse Flattening  = 298.2572221010

 Specified Order of Accuracy : 1st


 -------------------------------------------------------------------------------
  Common Stations

  Station  Station     Network          Latitude          Longitude    Ell.Height
  Number   Name        File              (D M S)           (D M S)        (m)
 -------------------------------------------------------------------------------

      1    89X003      base.dat     53 33 53.84837  -112 24 35.78287   669.794
                       test1.dat    53 33 53.84725  -112 24 35.78052   669.818

      2    77X251      base.dat     53 34 14.38388  -113 10 25.59619   684.944
                       test1.dat    53 34 14.38388  -113 10 25.59619   684.944

      3    78X000      base.dat     53 34 14.44215  -113 11 44.79469   670.374
                       test1.dat    53 34 14.44394  -113 11 44.79026   670.400

      4    89X004      base.dat     54  2  9.94409  -113  9 18.99992   616.917
                       test1.dat    54  2  9.94414  -113  9 18.99861   616.908

      5    89X002      base.dat     53 39 27.23137  -113 11 35.51892   619.886
                       test1.dat    53 39 27.23218  -113 11 35.52023   619.924

      6    89X005      base.dat     53 35 57.84741  -114 43 13.64524   767.804
                       test1.dat    53 35 57.84636  -114 43 13.64540   767.821

      7    89X001      base.dat     53 34  7.72900  -113  2 48.29376   715.984
                       test1.dat    53 34  7.72997  -113  2 48.29439   715.978

      8    89X006      base.dat     52 41 30.62300  -113 14 43.24432   763.832
                       test1.dat    52 41 30.62211  -113 14 43.24461   763.799

 -----------------------------------------------------------------
```

Coordinate Discrepancies (Test - Base)

Station Number	Station Name	dy (N) (m)	dy (E) (m)	dz (V) (m)
1	89X003	-0.035	0.043	-0.001
2	77X251	0.000	0.000	0.000
3	78X000	0.055	0.082	0.002
4	89X004	0.002	0.024	0.000
5	89X002	0.025	-0.024	0.001
6	89X005	-0.032	-0.003	-0.001
7	89X001	0.030	-0.012	0.001
8	89X006	-0.028	-0.005	-0.001

Strain Matrices

Station Number	Station Name	exx (str) / eyx (str)	exy (str) / eyy (str)
1	89X003	0.4658328E-07	-0.6823612E-06
		0.4464989E-06	0.8605682E-06
2	77X251	0.6075827E-06	-0.1178431E-05
		0.1048417E-06	0.5353372E-06
3	78X000	-0.2745578E-03	-0.7970402E-05
		-0.9193892E-03	-0.2840268E-04
4	89X004	-0.7547280E-06	-0.1550597E-05
		0.8579965E-06	0.1307838E-05
5	89X002	0.0000000E+00	0.0000000E+00
		0.0000000E+00	0.0000000E+00
6	89X005	-0.3231260E-03	-0.9366698E-05
		-0.9648183E-03	-0.2972161E-04
7	89X001	-0.5009041E-06	0.5564583E-06
		0.4236560E-07	0.2041102E-06
8	89X006	0.0000000E+00	0.0000000E+00
		0.0000000E+00	0.0000000E+00

Strain Parameters

Station Number	Station Name	2D Spec (ppm)	Diff. Rot. (ustr)	Pass/ Fail	Major Axis (ustr)	Minor Axis (ustr)	Major Az (deg)	Pass/ Fail
1	89X003	20	-0.6	Pass	0.9	0.0	98	Pass

2	77X251	20	-0.6	Pass	1.1	0.0	317	Pass
3	78X000	20	455.7	Fail	-631.2	328.3	38	Fail
4	89X004	20	-1.2	Pass	1.4	-0.8	99	Pass
5	89X002	20	0.0	N/A	0.0	0.0	0	N/A
6	89X005	20	477.7	Fail	-685.1	332.3	37	Fail
7	89X001	20	0.3	Pass	-0.6	0.3	340	Pass
8	89X006	20	0.0	N/A	0.0	0.0	0	N/A

TEST1.PLT

Output plot data file from NETSTR for BASE.DAT & TEST1.DAT analysis (input file for PLTSTR).

```
CCS 1990 GPS Validation Survey
Perturbed CCS 1990 GPS Validation Survey: 0.03m random error
           8           2          28
           1
    53.5649578802778        -112.409939685556         669.794500000000
  -0.345675E-01   0.432744E-01   0.234000E-01
  -0.564430E-06
   0.877310E-06   0.298416E-07          98
           2
    53.5706621888889        -113.173776719444         684.944300000000
   0.000000       0.000000       0.000000
  -0.641636E-06
   0.110947E-05   0.334512E-07         317
           3
    53.5706783752778        -113.195776303056         670.374000000000
   0.551596E-01   0.815312E-01   0.256000E-01
   0.455709E-03
   0.328256E-03  -0.631217E-03         128
           4
    54.0360955813889        -113.155277756667         616.917000000000
   0.157698E-02   0.239168E-01  -0.940000E-02
  -0.120430E-05
   0.136443E-05  -0.811318E-06          99
           5
    53.6575642680556        -113.193199700833         619.885900000000
   0.252611E-01  -0.240417E-01   0.383000E-01
   0.000000
   0.000000       0.000000               0
           6
    53.5994020575000        -114.720457012222         767.803600000000
  -0.323729E-01  -0.285078E-02   0.171000E-01
   0.477726E-03
   0.332281E-03  -0.685129E-03         127
           7
    53.5688136119444        -113.046748268056         715.983500000000
   0.298062E-01  -0.115401E-01  -0.570000E-02
   0.257046E-06
   0.314106E-06  -0.610900E-06          70
           8
    52.6918397233333        -113.245345644444         763.832300000000
  -0.276380E-01  -0.544736E-02  -0.329000E-01
   0.000000
   0.000000       0.000000               0
          91           2           3
          91           2           7
          91           2           5
          91           4           1
          91           3           6
          91           3           7
          91           7           4
          91           7           6
          91           2           5
          91           2           1
          91           2           8
          91           2           3
          91           2           7
          91           2           5
```


91	2	3
91	2	7
91	2	5
91	4	1
91	3	6
91	3	7
91	7	4
91	7	6
91	2	5
91	2	1
91	2	8
91	2	3
91	2	7
91	2	5

TEST2.STR

Output listing from NETSTR for BASE.DAT & TEST2.DAT input network data files.

```
-------------------------------------------------------
 NETSTR:  Network Strain Analysis
          Version 1.0 (20 Apr 90)
 Copyright (c) 1990 Geodetic Research Services Limited
-------------------------------------------------------

Piece-Wise Linear Approximation -- Connected Stations

1st (base) Network : base.dat
CCS 1990 GPS Validation Survey
Fixed Station: 77X251

2nd (test) Network : test2.dat
Perturbed CCS 1990 GPS Validation Survey: rand=0.03m,dx=0.1m,rotz=10",ds=2ppm
Fixed Station: 77X251

Output Plot Data File : test2.plt

Ellipsoid Parameters:
  Major Semi-Axis (m) =    6378137.000
  Inverse Flattening  = 298.2572221010

Specified Order of Accuracy : 1st


-------------------------------------------------------------------------------
 Common Stations

 Station  Station     Network         Latitude         Longitude    Ell.Height
 Number   Name        File             (D M S)          (D M S)        (m)
-------------------------------------------------------------------------------

     1    89X003      base.dat     53 33 53.84837  -112 24 35.78287   669.794
                      test2.dat    53 33 53.92978  -112 24 35.77258   669.818

     2    77X251      base.dat     53 34 14.38388  -113 10 25.59619   684.944
                      test2.dat    53 34 14.38711  -113 10 25.59619   684.944

     3    78X000      base.dat     53 34 14.44215  -113 11 44.79469   670.374
                      test2.dat    53 34 14.44488  -113 11 44.79043   670.400

     4    89X004      base.dat     54  2  9.94409  -113  9 18.99992   616.917
                      test2.dat    54  2  9.95265  -113  9 19.13647   616.909

     5    89X002      base.dat     53 39 27.23137  -113 11 35.51892   619.886
                      test2.dat    53 39 27.23402  -113 11 35.54591   619.924

     6    89X005      base.dat     53 35 57.84741  -114 43 13.64524   767.804
                      test2.dat    53 35 57.68907  -114 43 13.66215   767.823

     7    89X001      base.dat     53 34  7.72900  -113  2 48.29376   715.984
                      test2.dat    53 34  7.74638  -113  2 48.29291   715.978

     8    89X006      base.dat     52 41 30.62300  -113 14 43.24432   763.832
                      test2.dat    52 41 30.61158  -113 14 42.99266   763.799

-----------------------------------------------------------------
```

Coordinate Discrepancies (Test - Base)

Station Number	Station Name	dy (N) (m)	dy (E) (m)	dz (V) (m)
1	89X003	2.517	0.189	0.081
2	77X251	0.100	0.000	0.003
3	78X000	0.085	0.078	0.003
4	89X004	0.265	-2.485	0.009
5	89X002	0.082	-0.496	0.003
6	89X005	-4.896	-0.311	-0.158
7	89X001	0.537	0.016	0.017
8	89X006	-0.353	4.727	-0.011

Strain Matrices

Station Number	Station Name	exx (str) eyx (str)	exy (str) eyy (str)
1	89X003	0.2045692E-05 -0.4858827E-04	0.4778054E-04 0.3133289E-05
2	77X251	0.2607396E-05 -0.4744911E-04	0.4729104E-04 0.2891636E-05
3	78X000	-0.2744216E-03 -0.9125157E-03	0.4046829E-04 -0.2516876E-04
4	89X004	0.1242541E-05 -0.4758434E-04	0.4746049E-04 0.3625684E-05
5	89X002	0.0000000E+00 0.0000000E+00	0.0000000E+00 0.0000000E+00
6	89X005	-0.3229388E-03 -0.9597842E-03	0.3910654E-04 -0.2654023E-04
7	89X001	0.1498342E-05 -0.4899633E-04	0.4905097E-04 0.1698471E-05
8	89X006	0.0000000E+00 0.0000000E+00	0.0000000E+00 0.0000000E+00

Strain Parameters

Station Number	Station Name	2D Spec (ppm)	Diff. Rot. (ustr)	Pass/ Fail	Major Axis (ustr)	Minor Axis (ustr)	Major Az (deg)	Pass/ Fail
1	89X003	20	48.2	Fail	3.3	1.9	108	Pass

2	77X251	20	47.4	Fail	2.9	2.6	105	Pass
3	78X000	20	476.5	Fail	-603.3	303.7	37	Fail
4	89X004	20	47.5	Fail	3.6	1.2	91	Pass
5	89X002	20	0.0	N/A	0.0	0.0	0	N/A
6	89X005	20	499.4	Fail	-658.3	308.9	36	Fail
7	89X001	20	49.0	Fail	1.7	1.5	82	Pass
8	89X006	20	0.0	N/A	0.0	0.0	0	N/A

TEST2.PLT

Output plot data file from NETSTR for BASE.DAT & TEST2.DAT analysis (input file for PLTSTR).

```
CCS 1990 GPS Validation Survey
Perturbed CCS 1990 GPS Validation Survey: rand=0.03m,dx=0.1m,rotz=10",ds=2ppm
           8           2          28
           1
    53.5649578802778        -112.409939685556         669.794500000000
    2.51712       0.189443       0.237000E-01
   0.481844E-04
   0.326686E-05   0.191213E-05         108
           2
    53.5706621888889        -113.173776719444         684.944300000000
   0.999925E-01   0.000000       0.000000
   0.473701E-04
   0.291214E-05   0.258690E-05         105
           3
    53.5706783752778        -113.195776303056         670.374000000000
   0.845018E-01   0.784945E-01   0.256000E-01
   0.476492E-03
   0.303690E-03  -0.603280E-03         127
           4
    54.0360955813889        -113.155277756667         616.917000000000
   0.264562      -2.48532      -0.830000E-02
   0.475224E-04
   0.362729E-05   0.124093E-05          91
           5
    53.6575642680556        -113.193199700833         619.885900000000
   0.822144E-01  -0.495582       0.384000E-01
   0.000000
   0.000000       0.000000              0
           6
    53.5994020575000        -114.720457012222         767.803600000000
  -4.89589      -0.310956       0.190000E-01
   0.499445E-03
   0.308867E-03  -0.658346E-03         126
           7
    53.5688136119444        -113.046748268056         715.983500000000
   0.537408       0.157917E-01  -0.560000E-02
   0.490236E-04
   0.170213E-05   0.149468E-05          82
           8
    52.6918397233333        -113.245345644444         763.832300000000
  -0.353049       4.72710      -0.328000E-01
   0.000000
   0.000000       0.000000              0
          91           2           3
          91           2           7
          91           2           5
          91           4           1
          91           3           6
          91           3           7
          91           7           4
          91           7           6
          91           2           5
          91           2           1
          91           2           8
          91           2           3
          91           2           7
          91           2           5
```

91	2	3
91	2	7
91	2	5
91	4	1
91	3	6
91	3	7
91	7	4
91	7	6
91	2	5
91	2	1
91	2	8
91	2	3
91	2	7
91	2	5

