

HAVOC

HORIZONTAL ADJUSTMENT BY VARIATION OF COORDINATES

USER DOCUMENTATION

Version 3.6.10

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**LAND AND PROPERTY INFORMATION
DEPARTMENT OF FINANCE AND SERVICES**

BATHURST

April 2014

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1. INTRODUCTION

This documentation has been prepared to provide information to users of the program HAVOC (Horizontal Adjustment by Variation Of Coordinates). The Department of Lands has used computer programs for the least squares adjustment of geodetic survey observations since 1961.

The purpose of this documentation is to describe the current version of a program that has undergone many years of development, testing and enhancement for specific application to the geodetic and mapping control survey functions of the Land and Property Information Division of the Department of Lands.

The version of the program described in this documentation is HAVOC Version 3.6. It runs on HP computers using the Unix operating system. It has also been compiled for IBM compatible personal computers using the Microsoft DOS compiler and in 2003 was modified for compilation using the G77 NT compiler for Windows and Linux operating systems.

The documentation contains descriptions of functions provided by the program for the work of the Department of Lands.

1.1 Development History

The first adjustment program used by the Department of Lands was written in 1961 for the UTECOM computer at the University of NSW. It accepted a coefficient matrix and absolute terms as input data, generated and solved the normal equations and produced the solution and residuals on observations after adjustment. As the processing was limited to matrix manipulation, the program could carry out an adjustment using either condition or parametric techniques.

In 1964 the program was rewritten in assembler language for the Honeywell 400 computer. This program, called LTGCQ1, had the same functions available as the UTECOM program.

LTGCQ1 was extended in 1966 to accept input in the form of provisional coordinates and distance and direction observations. The program LTGCQ2 reduced the observations, formed the coefficient matrix and normal equations, solved the normal equations and produced a comprehensive listing of results. The variation of coordinates adjustment technique was used.

In 1969, with the introduction of the Honeywell 1800 computer, the program LTGCQ2 was rewritten in Fortran. This version, titled LCOMPS, incorporated the banded matrix solution techniques similar to the program VARYCORD used by the Division of National Mapping.

LCOMPS was modified to run on the Department's PDP 11/45 computer in 1972. This program was named HAVOC.

The program was enhanced between 1975 and 1977 to provide error ellipses after adjustment and for optimisation. This required the addition of the extra processing needed for the inversion of the normal matrix.

During this period the program was linked to the Geodetic Control Register for the retrieval of geodetic station information. The ability to process azimuth observations was also included and output was improved to provide more information for the statistical analysis of the results of the adjustment.

In 1981 the program was considerably enhanced to allow the input of eccentric stations, the storage of eccentric information, the reduction to centre of observations and the automatic computation of provisional coordinates. Information produced by the program for adjustment analysis was also improved.

The program was again modified in 1986 to allow the automatic disk storage of intervisibility data for geodetic stations and to allow the input of height differences between eccentric stations for verification purposes. Default options were also modified for frequently required options. These modifications resulted in a version called HAVOC V4.2.

In 1987 the program was converted to run on a VAX 11/750 computer. More enhancements were made mainly to improve the data error detection and reporting capabilities. The capacity of the program in some areas was also increased.

In February 1989 the capability of using bearing observations to compute provisional coordinates was added. At the same time a new input record allowing the input of bearing and distance data was included. This version was named HAVOC VAX-2.0.

A further modification based on the entry of bearing and distance data was made in May 1989. This was to allow the allocation of an orientation unknown for a set of bearings. By using this additional unknown, an orientation value for a set of bearings can be determined in an adjustment. This was included specifically for coordinated cadastral applications. For these, the ability to rotate a set of bearings obtained from a survey plan to fit control points is necessary.

In July 1989 the program was again enhanced so that adjustments could be computed using the WGS72 and WGS84 ellipsoids. This allowed the use of the program outside the limits of the AMG coordinate system. This version of the program was named HAVOC VAX-2.1.

HAVOC Version 2.2, for the Unix and DOS operating systems, was created in May 1990 with the inclusion of auxiliary parameters for the determination of adjusted scale corrections for sets of distances. Improvements were also made to the provisional coordinate computation process by including a search for reverse bearing and azimuth observations. This version was compiled using the HP-UX compiler in January 1991 and also the Microsoft DOS compiler.

HAVOC Version 3.0 was created in July 1994 by incorporating geoid-ellipsoid separation models for ANS and WGS84 for the reduction of distances to the ellipsoid. Distance reduction options were also extended and the capability of processing three dimensional cartesian coordinate difference observations was included.

Version 3.1 was created in December 1996 by including a modified input format which allowed the use of an alphanumeric station label instead of a number. This format allowed observation data to be entered with a twelve character station label. This caters for the SSM and PM labels used for survey control work within the organization. At this time the program was also

modified to make more use of memory wherever possible to reduce the amount of disk accessing during the solution and inversion of the normal matrix.

Version 3.2 and then 3.3 were developed between 1996 and 2001 by making general improvements such as adding the capability of retrieving data from a variety of files. Also added was the option for creating output files with a variety of formats.

Transformation to GDA94 was also included with other options that could assist with the conversion of AGD66 networks using AMG or ISG coordinates.

Versions 3.4, 3.5 and 3.6 were produced in 2002 and 2003, allowing greater flexibility in input formats and providing more output for the analysis of the results of the adjustment. This was becoming an important requirement as the size of the adjustment data sets increased.

1.2 Development Status

HAVOC Version 2.2 was made available for IBM compatible PC in December 1990. Since that time it has been used extensively for the work of the Lands Department and also of other Government organizations and private surveyors. During this period of use, reports from users were received to identify some minor bugs and some minor improvements.

All reported defects in this version were removed and suggested improvements were implemented. The source code and DOS executable for this version are still available and have been used for testing later versions.

Version 3.6 has been used and distributed since December 2003 and is being improved as suggestions from users are received. The in-house requirement for the processing of archived data sets within the organization has always been considered during the development and this function is still available.

1.3 Functions of the Program

The program performs the following functions for the geodetic and survey control activities of the Department of Lands.

- The computation of coordinates from field observations using the methods of radiation, resection, intersection and three dimensional cartesian coordinate differences.
- The adjustment of networks by the parametric method (variation of coordinates) using local coordinates, AMG and ISG grid coordinates based on the Australian National Spheroid, UTM grid coordinates based on WGS72 and MGA94 grid coordinates on GDA94 datum.
- A statistical analysis of adjustment results using error ellipse and residual analysis output.
- The analysis of networks of triangulation and trilateration for the purpose of optimization.

- The creation of adjusted coordinate and observation files for the plotting of network diagrams and for updating information in geodetic data bases.

1.4 Standard Fortran Version

In November 1989 the program code was converted to standard Fortran to run on HP minicomputers using the Unix operating system. The conversion to standard code has allowed compilation of the program using the Microsoft Fortran compiler, the Lahey compiler and the G77 compiler for IBM compatible personal computers and for Linux minicomputers.

1.5 Operation of the Program

HAVOC reads data for an adjustment from a text file formatted according to the specification given in Section 3. All adjustment options are contained in the input file.

To run the program the word 'havoc' should be entered at the Unix or Command prompt. The names of the input file and output file can also be entered on the command line. If the input file name alone is entered, the program derives the output file name from the input file name by appending the extension ".prt". This indicates that it is a file for printing or viewing.

If an existing output file is found the program displays a message and waits for a response by the user to indicate whether it should be overwritten or not. The default response is 'y'.

If the first command line argument is '-o' the existing output file message is not displayed and the new output file will overwrite an existing file. A first command line argument of '-m' can be used to suppress all messages that usually appear on the screen.

If the input file name is entered without an extension it is assumed to have an extension of '.hav'.

If no command line arguments are entered, the program looks for a file called 'havoc.cmd' and reads command line arguments from the first record of this file. If the command line argument file is not available, the program requests the name of an input file. In this case also, the output file name is derived from the input file name.

1.6 Matrix Processing

The most time consuming function of HAVOC for large adjustments is the solution and inversion of the normal matrix. Because of memory limitations, earlier versions of the program stored and performed matrix computations using work files on disk.

The amount of reading and writing necessary for this matrix manipulation has been reduced in later versions of the program because of the availability of more memory. The current version of the program uses two two-dimensional arrays for matrix workspace. The size of these arrays,

which can easily be set before program compilation, depends on the amount of memory available in the computer being used.

The program calculates the amount of matrix workspace it needs for the current job. If it can store the matrix in the arrays it has available, the solution, and if required the inversion, will be computed in memory. More storage space is necessary for inversion so the size of matrix that can be stored in memory will be less if the matrix inversion option is selected.

If insufficient workspace is available, the program creates work files on disk for the computation. When work files are used the workspace in memory is used as a buffer area or cache in which work file records are stored and transferred between memory and disk as required.

To reduce the time required for matrix inversion, the program does not normally process rows related to orientation parameters or auxiliary parameters. These are automatically omitted unless the option for full matrix inversion is selected. This option should be needed only for testing the matrix inversion process or for providing an inverted matrix to another program.

The NT versions of the program are able to access memory in the same way as other Windows programs so the matrix work area allocated by the program is very large. For most adjustments the matrix processing will be done in memory. This increases the speed of the matrix operations.

1.7 G77 Compiler

In July 2002 the source code was modified and compiled using the G77 compiler. The program produced by this compiler is an NT program that has access to the large amount of NT memory available for the storage of matrix terms. For most adjustments the entire normal and inverse matrix can be stored in memory. This increases the speed of the adjustment process.

Using this compiler two larger capacity versions have been created one for 2000 stations and another for 4000 stations.

The NT version of the program does not have the DOS restriction on the length of file names.

1.8 Allocation of Files to Disk Drives

The PC version of HAVOC allows the allocation of specific disk drives to be used for input, output and work files. For the DOS version, processing time could be reduced by assigning work files to a RAMDRIVE. This was often set up to utilise extended memory. When network drives are being used, the processing time is reduced if work files are opened on the local drive.

Disk drives are assigned using an options file that HAVOC reads if it is available. This file can be edited to set the required disk drives. The file format is described in Section 3.1.4.2.

The option file can also be used for attaching a directory path to most files used by the program for Unix, DOS and NT versions.

1.9 Relationship with Program TRGLEV

The vertical adjustment program TRGLEV was developed to determine station heights for network adjustments in conjunction with HAVOC. Because of this, the HAVOC data record types are compatible with TRGLEV. The station record is the same and observation records are similar with unique record identifiers being used for horizontal and vertical observations. Horizontal and vertical observations can be entered in the same input file.

The output of both programs contains similar information so that a user familiar with one program should easily be able to interpret the output of the other.

For the solution and inversion of the normal matrix, HAVOC and TRGLEV use the same algorithms and subroutines.

HAVOC and TRGLEV can be run iteratively for the three dimensional adjustment of a network. A program called HAVLEV is available for this.

1.10 Program Modification Summary

Major modifications made to the program to create recent versions are itemised below.

HAVOC VAX 2.0, February 1989

- . Bearing and distance record added.
- . Computation of provisional coordinates from bearings and distances included.

HAVOC VAX 2.1, July 1989

- . The capability of allocating auxiliary orientation parameters for sets of bearings included.
- . Improved equations for geodetic transformation, including WGS72 and WGS84, added.
- . Reduction of distances using station heights added.
- . Automatic insertion of stations from observation data included.
- . Extended statistical analysis of residuals.

HAVOC Version 2.2, December 1990

- . The capability of allocating auxiliary parameters for scale unknowns for sets of distances included.

- . Computation of provisional coordinates from azimuths and reverse bearings and reverse azimuths included.
- . Modification for suppression of the centering standard deviation for selected observations when required.
- . Modification for suppression of station summary and intervisibility information when required.
- . Matrix solution and inversion algorithm modified to do more processing in memory.

HAVOC Version 3.0, January 1995

- . Extended distance reduction options.
- . Geoid-ellipsoid separation models for ANS and WGS84 included.
- . Capability of accepting three dimensional cartesian coordinate difference observations added.
- . Modified to allow use with TRGLEV for an iterative three dimensional network adjustment.

HAVOC Version 3.1, November 1996

- . Station label format included for most observations.
- . Capacity of program increased.
- . Optimised the use of computer memory to reduce number of disk accesses for matrix solution and inversion.

HAVOC Version 3.2, August 1998

- . Additional station label format for observations.
- . The ability to read station data from a variety of files added.
- . The ability to create output files with a variety of formats added.
- . Change of ellipsoid parameters from WGS84 to GRS80 for adjustments using the GDA94 datum.
- . Addition of the option to transform coordinates from AGD66 to GDA94.

HAVOC Version 3.3, January 2001

- . Improvements for AGD66 to GDA94 conversion
- . Improvements in access to station data files.
- . The addition of observation class calculated from relative error ellipses.
- . The addition of a station connection file output for the analysis of the network.
- . The addition of station and observation file output for the display of the network using the TCL plotting system.
- . Minor modifications to source code for implementation on IBM high performance computer running AIX.
- . General improvements in processing with unusual combinations of options.

HAVOC Version 3.4, April 2002

- . The ability to read tab separated data for processing DP data was added
- . An option was added for the identification of observations and removal of distances between fixed stations.
- . An option was added for the output of connection information and error ellipses for unconnected stations.
- . An option was added to read into the input file the adjusted station coordinate records.
- . An option was added to temporarily constrain stations that are radiated for an unconstrained adjustment.

HAVOC Version 3.5, April 2003

- . The output of the plotting file, the connection information file and the SCIMS report file were automatically selected.
- . An NT version of the program was developed using the G77 compiler.
- . An option to read a free format option record was added.
- . The conversion of ISG projection data included with MGA data was added.
- . An option to produce a report on distance reduction was added.
- . The processing of a supplementary adjustment using label format was activated.

HAVOC Version 3.6, May 2011

- . Adjustment report output added to provide statistics for the analysis of input data, adjustment network and adjustment results.
- . Improvement in distance reduction report.
- . Improvement in station connection report.
- . New option for selecting order of stations in SCIMS file to be held fixed.
- . Improvement in some error messages.
- . Increased matrix work space for NT versions.
- . Command line options for suppression of screen output added.
- . Distance check included in report file.

HAVOC Version 3.6, November 2011

- . Updated GRS80 Geoid model with AUSGEOID09 values.
- . Modified SCIMS CSV file access for SIX SCIMS output file.
- . Removed the cause of error when reading old format Unix files.
- . Included report for cartesian coordinate computations.
- . Modified adjustment report file.
- . Improved error messages.

HAVOC Version 3.7, August 2008

This version of the program is based on Version 3.6 with all functions related to AGD66 and ISG removed. The specific items removed are the following.

- . AGD66, ISG, ANG and WGS72 ellipsoid and projection parameters.
- . AGD66 geoid model.
- . MRE transformation from AGD66 to GDA94.
- . Conversion from ISG to AMG.
- . Conversion of ISG bearing and distance data.

- . Access to the Geodetic Control Register

HAVOC Version 3.8, November 2011

- . Included latest modifications in Version 3.7 from Version 3.6.
- . Added option for converting GPS baselines to easting and northing coordinate differences.
- . Added easting and northing difference observation type.
- . Included option for adding datum and projection information using an ARC PRJ file.

HAVOC Version 4.2, August 2008

This was created by adding to HAVOC Version 3.7 the processing for observation reliability and correlation analysis which was developed for the program ORCA. Additional output from this version can be used to analyze residual outliers, observation redundancy and marginally detectable errors based on the observation weights and network structure.

More information on this version is given in Appendix F.

HAVOCL version 3.6, August 2008

Increased capacity versions were created for large adjustment networks. HAVOCL can be used for up to 2000 stations and 12000 observations. HAVOCXL can be used for up to 4000 stations and 20000 observations. These have the same functions as HAVOC 3.6.

2. FUNCTIONS OF HAVOC

HAVOC provides an extensive range of functions in addition to the basic function of a least squares adjustment. These have been incorporated to provide users with facilities needed for geodetic data processing within the organization. The functions of the program are described in this section.

2.1 Introduction

HAVOC was originally developed to compute the least squares adjustment of triangulation networks, trilateration networks and networks combining both of these. After many years of development the program now provides the following main functions.

- Computation of provisional coordinates using observations supplied for the adjustment.
- Output of geographic coordinates for all stations in the adjustment.
- Computation of azimuth and distance information between connected or selected stations.
- Computation of relative ellipses for observed and selected lines.
- Computation of point error ellipses for each adjusted station.
- Output of class for each observation based on error ellipse size.
- Output of additional information for analysis of the adjustment.
- Transformation of station coordinates from ISG or AMG66 to MGA94.
- Access to a variety of file types for input of station information.

2.2 Observation Types Processed

A variety of observation types can be processed by HAVOC to obtain a least squares solution for the parameters used in the adjustment. The adjustment parameters are corrections to provisional coordinates and corrections to provisional values for the auxiliary parameters used in the adjustment. The types of observations that can be accepted by the program are described below.

2.2.1 Laplace Azimuth

An azimuth can be entered as an astronomically derived value to which a Laplace correction and a deflection correction are applied. When this type of observation is entered, the

astronomical latitude and longitude and elevation angle must also be available. The elevation angle can be entered or the program will compute it from station heights.

The astronomical azimuth is converted to a plane bearing by applying Laplace correction, deflection correction, grid convergence and arc-to-chord correction.

A Laplace observation from an unfixd station can be entered even though it is possible that the adjustment will cause a change in the geodetic longitude. An error in the computed Laplace correction due to a small error in geodetic longitude is compensated for by an error in the computed grid convergence of the same magnitude and opposite sign. This will apply as long as the longitude is reasonably close.

2.2.2 Azimuth

An azimuth between two stations can be entered into the adjustment as an observation. The value entered is converted to a plane bearing by applying grid convergence and arc-to-chord correction.

2.2.3 Bearing

A plane bearing between two stations can be entered similarly to an azimuth. The value is used as entered. When transforming a dataset from ISG to MGA a bearing can be indicated as an ISG bearing. This is converted to an azimuth by applying the ISG grid convergence. The azimuth is then used for the adjustment on the GDA94 datum.

This allows ISG and MGA bearings to be included in the same data set.

2.2.4 Direction

Observed directions can be entered as a set of at least two directions from a station. Multiple sets can be entered up to a maximum of thirty sets from any one station. The number of directions in one set is limited to 80.

Directions are oriented by the program using the first direction of the set and converted to plane bearings by applying arc-to-chord corrections.

For each set of directions entered an unknown orientation parameter is included in the normal matrix. A solution for this unknown will be obtained in the adjustment.

If eccentric mark numbers are entered in the direction record the direction is reduced to centre using the eccentric data stored in the geodetic station eccentric mark database.

2.2.5 Distance

Ellipsoidal distances are required for the adjustment. The program converts these to plane distances by applying the line scale factor.

The program allows the entry of different forms of distance by providing distance reduction functions to convert the value entered to an ellipsoidal value. There are several options available in the program for the reduction of distances. Atmospheric corrections are assumed to have been applied to distances entered.

A distance can be entered in a number of ways. The types of distances accepted by the program are described below.

- Mark to mark chord distances. These distances are also referred to as spatial distances. When spatial distances are to be projected onto the ellipsoid or a plane they are reduced as if they are slope distances. For these, the heights of the stations must be entered in the station records. The distance is reduced to the height datum used. (See Section 2.26)
- Instrument to reflector distances. In this case the height of instrument and the height of reflector must be entered in the distance record as well as the heights of the occupied and observed stations in the station records. The distances will be reduced to the height datum used. This will usually be mean sea level. (See Section 2.26)
- Horizontal distances at ground height. The distance is reduced using the height of the occupied station.
- Mean sea level arc distances. In most cases no further reduction is required for these although, for geodetic projects, they may need to be reduced to the ellipsoid. This is necessary because of the separation between the geoid and the ellipsoid that must be taken into account for geodetic work. There is an option in the program for this. More information on this is available the GDA Technical Manual published by ICSM.
- Distances required to be reduced to a specific height datum. A height datum value can be entered in the '22' record or, if the label format is used, a height datum record of type 'hgt' can be used. The latter technique can be used to supply one value for the whole network. The '22' record can be used to supply a different value for each distance.
- Ellipsoidal arc distances. These distances need no further reduction. They are converted to plane distances by the program by applying the line scale factor for the selected grid.
- Plane distances. These do not require the application of the line scale factor.

2.2.6 Three Dimensional Cartesian Coordinate Differences

Although the adjustment is not three dimensional, cartesian coordinate differences can be entered as observations. These are converted to either azimuths and spatial distances or bearings and ellipsoidal distances before the adjustment. When a network consists mainly of terrestrial observations this type of observation can be used as a constraint for the adjustment.

As for bearing and distance observations, coordinate differences can be assigned a standard deviation for the derived azimuth and distance. When an azimuth standard deviation is not

entered it is computed using the distance standard deviation and length of the line. This will produce a standard deviation perpendicular to the line equal to the standard deviation value along the line.

Azimuth and distance components can also be associated with auxiliary parameters for rotation and scale that are solved for in the adjustment.

2.2.7 Position

An observation equation representing a coordinate observation for an easting or a northing value for a station can be included. When a standard deviation for the easting or northing is entered with the station information, a position observation for either the easting or northing is included.

This type of observation provides a constraint on the movement of a station without fixing it.

2.2.8 Auxiliary Parameters

Auxiliary parameters representing scale and rotation corrections can be introduced into an adjustment. Rotation parameters can be included in the adjustment by entering sets of bearings or azimuths. A rotation parameter is included for each set. This is described in Section 2.14.

Scale parameters can be introduced into the adjustment by grouping distances into sets. One parameter is included for each set of distances. This is described in Section 2.30.

2.3 Adjustment Grid

Adjustments are carried out on either an arbitrary plane or a choice of four Transverse Mercator grids.

- The Australian Map Grid (AMG) based on the Universal Transverse Mercator projection (UTM) between zones 49 and 57, and the Australian National Spheroid.
- The New South Wales Integrated Survey Grid (ISG) which is based on the AMG. Each six degree zone is divided into three 2 degree zones.
- The Universal Transverse Mercator grid for zones 1 to 60 on the World Geodetic System (WGS72) spheroid.
- The Universal Transverse Mercator grid for zones 1 to 60 using the GRS80 ellipsoid. Within Australia this is known as the Map Grid of Australia (MGA94) which is based on the Geocentric Datum of Australia (GDA94).

2.3.1 Units of Measurement

Units of measurement are metres.

2.3.2 Projection Corrections

If the adjustment is using an arbitrary plane grid, observations will be assumed to be plane. If the adjustment is to be on an ISG, AMG, MGA or UTM grid, then observations may be entered as either ellipsoidal or plane observations. In the former case arc-to-chord reduction and line scale factor are applied. In the latter case the reductions are not required. This option can be selected in the option record.

2.4 Stages of Processing

Processing is carried out in four distinct stages. Processing may be terminated after any one of these stages by the entry of a parameter in the option record. This option has been made available so that observation data can be examined for gross errors before a considerable amount of computer time is utilised in computing the adjustment. Another reason for this option is that the stage three and stage four output was designed specifically for use by the Lands Department and may not be required by other users.

2.4.1. Stage One

Stage one of the processing consists of the following functions.

- Reading and validation of input data.
- Re-arrangement of the station input order to achieve minimum width of diagonal band of the normal matrix.
- Computation of provisional coordinates.
- Retrieval of station information from a variety of file types.
- Checking of observation data for gross errors.
- Formation of observation equations.

2.4.2 Stage Two

Stage two of the processing consists of the following functions.

- Formation and solution of normal equations.
- Inversion of the normal matrix if required.
- Computation of residuals, adjusted coordinates and error ellipses if required.

2.4.3 Stage Three

Stage three of the processing consists of the following functions.

- Computation of geographical coordinates.
- Computation of azimuths and distances for geodetic station summaries.

2.4.4 Stage Four

Stage four of the processing consists of the following function.

- Creation of a file of adjusted coordinates for use by other programs.

2.5 Mathematical Method

Details of the mathematical theory of least squares adjustments for surveying applications are described in Appendix A of this documentation. The mathematical techniques used by HAVOC are well explained in “Practical Least Squares and Statistics for Surveyors” by Bruce Harvey published by the University of New South Wales.

A general description of the method is that provisional coordinates for all stations are either entered in the input data file, computed by the program or retrieved from other files. The value of each observation entered is compared with the value computed from the provisional coordinates.

When these computed and observed values are compared, excluding gross errors, small differences will be found. The objective of the adjustment is to compute corrections to the provisional coordinates such that the weighted sum of the squares of the differences between observed and adjusted values of the observations is minimised.

The program takes advantage of the following features of the variation of coordinates method.

- . No conditions need be determined.
- . The number of unknown parameters can easily be obtained, being twice the number of stations to be adjusted, plus one for each set of directions, bearings and distances.
- . Adjusted coordinates are readily produced directly from the solution of the normal equations.

2.6 Supplementary Adjustment

This term is used within the Lands Department and throughout this documentation for an adjustment of a small network consisting of a geodetic station, its eccentric marks and distant orientation stations. The main station mark is usually a concrete pillar connected by directions

and distances to the eccentric marks that are also inter-connected. The orientation stations are always held fixed in the adjustment.

For this type of adjustment, station height values are interpreted as differences in height between the main station and its eccentrics. When height difference observations are read by the program, the information is used to verify the station height differences entered with the station data. Because the height values are height differences the reduction to sea level for distance observations is not possible.

2.7 Computation of Provisional Coordinates

The program will automatically compute provisional coordinates for stations using the observations supplied. The methods of radiation, resection, intersection and cartesian coordinate differences are used for this computation.

When a station without coordinate values is detected, the program searches through all observations for a direction and a distance or a bearing and a distance from a station with coordinates. If a direction is found there must also be a station with coordinates available to orientate the direction set.

If observations suitable for a radiation are not found, the program searches through all directions for sufficient directions observed to coordinated stations to compute a resection.

For a resection at least three directions are needed. If more than three suitable directions are found in a set, the first three are used to compute provisional coordinates and a maximum of seven more are used for a least squares solution. No more than ten observations are used for the computation

If observations are not available for either a radiation or a resection, the method of intersection is attempted. A search is made through all observations until two directions or a bearing and a direction to the station are found. For a direction to be suitable a search is also made to ensure an orientation direction for the set is available.

When two suitable observations have been found, the angle of intersection is calculated and if it is less than 10 degrees, the second observation is rejected and searching resumes for another one.

If three dimensional cartesian coordinate difference observations have been supplied these will be used to compute coordinates if insufficient terrestrial observations are available. When coordinate differences are used to compute coordinates and a height value has been entered for the station used for the computation, an ellipsoidal height will be computed with the coordinates. The height value will be converted to an orthometric height using the N value interpolated or supplied.

The order in which the stations are coordinated is the same as the order in which they are printed in the station output. The order in which the observations are searched through is the same as the order in which they are printed. Because of this, stations are coordinated by the first available observations. This may not be the optimal solution.

An iterative process is used for the coordination in which a count of the number of stations coordinated in each iteration is maintained. If, after two consecutive iterations, no stations have been coordinated the process is terminated.

2.8 Reduction to Centre

The reduction to centre of directions and distances was computed by the program whenever an eccentric number was supplied with an observation. This function is no longer applicable because the eccentric data needed by the program is not available. The function has been retained in the program for possible future use.

2.9 Re-iteration of Adjustment

When the provisional coordinates used for an adjustment are very approximate, it might be necessary to repeat the adjustment using the adjusted coordinates as the provisional coordinates for the next iteration. The program will carry out up to nine iterations of the adjustment to ensure that convergence occurs. This should be necessary only when estimates of provisional coordinates are of poor quality.

After each iteration, the program tests the corrections computed for each station. If none of the corrections exceeds two millimetres in size no further iterations of the adjustment are computed even if requested.

2.10 Computation of Geographical Coordinates

Geographical coordinates for all stations in an adjustment can be obtained by selecting stage three output for the adjustment. When this option is selected, the program provides a listing of all stations in the adjustment with geographical coordinates and also a summary of each station showing azimuth and distance to each station observed.

Geographical coordinate output may be obtained for any adjustment computed on any of the standard grids. If a station lies in a zone overlap, the coordinates in the overlapping zone will also be computed. If the adjustment is computed on AMG, then corresponding ISG coordinates will be computed, and vice-versa. The overlap zones used are one degree for TM, AMG and MGA and half a degree for ISG.

To save time and disk space the program will not provide this output if the adjustment variance factor exceeds the default value of 5.0. Usually an adjustment would need to be run again with modified data if the variance factor exceeds this value. The value of the limit can be modified if required using columns 77 to 79 of the option record.

2.11 Station Summaries

2.11.1 Main Adjustment

If the program is run to stage three, station summaries for each station in the adjustment can be obtained by selecting this option using column 48 of the option record. Each summary contains, in addition to all coordinate information for a station, a list of azimuths and ellipsoidal distances to each station connected to it by observation or selected using the method described in Section 2.12. Adjusted plane bearings and plane distances can also be obtained by selecting an expanded station summary using column 48 of the option record.

The azimuths and spheroidal distances are normally computed from AMG coordinates whether the adjustment is computed on AMG or ISG. If column 48 of the option record is used to select the expanded station summary, an ISG station summary will be obtained for ISG adjustments.

If required the expanded station summary will show ground distance values computed using the mean height of the connected stations.

2.11.2 Supplementary Adjustment

Normally a station summary for the main station only will be printed. An option is available for the selection of the printing of all station summaries for supplementary adjustments.

The main station SCIMS number is assumed to be the last station number entered with an eccentric mark number in either a '10' or an 'stn' record. If required the main station can be selected by entering a zero as the eccentric mark number. The supplementary adjustment summaries show eccentric stations and differences in height between each eccentric mark and the main station.

2.12 Request for Extra Azimuths and Distances

Azimuths and distances for lines not observed in the network can be obtained in the station summary. These are requested by inserting extra distance or direction observation records which contain only 'FROM' and 'TO' station numbers without an observation value. The total number of requests that can be made is 1000 and this is included in the total number of observations which is subject to the program limit.

This can be used for obtaining azimuths and distances between two stations without an adjustment being carried out. An option for this is available in the option record. It can also be used to compute azimuths and distances between stations using the provisional coordinates. This is explained in Section 2.24.

Output of the required azimuth and distance values are included in the station summary output which can be selected using column 48 of the option record.

2.13 Sets of Directions

The program allows up to twenty sets of directions to be entered from one station, so that data from different sources may be used in one adjustment. Each additional set adds one unknown to the normal matrix. This unknown is an orientation parameter for the set.

2.14 Sets of Bearings

Bearings entered with bearing and distance data can be grouped into sets of bearings. An orientation parameter is included for each set of bearings entered. This allows a set of bearings to rotate in the adjustment. The solution for the orientation parameter provides an orientation correction for the set.

The beginning of a new set of bearings is defined by the entry of a code in the bearing and distance record. Therefore there is no limit to the number of sets that can be included apart from the limitation on the matrix size.

2.15 Centering Standard Deviation

If required a centering standard deviation for the whole network can be entered using the option record. The value entered represents the combined centering standard deviations at the occupied and observed stations.

It is converted to an angular quantity using the length of the line. This is combined with the standard deviation entered with the direction or azimuth observation.

2.16 Automatic Minimizing of Bandwidth

The normal equations are solved by the Cholesky method. This method is particularly suited to solving a matrix in which the coefficients lie in a band about the main diagonal. The bandwidth is minimized by the program by optimizing the difference between sequence numbers of connected stations. As a result of this process the order of the stations in the adjustment and in the output file is changed. This process can be bypassed by entering a 'B' in column 11 of the option record.

2.17 File of Adjusted Coordinates

Adjusted coordinates can be written to a disk file to be used for the supply of station information to other programs. The production of this file is optional and will be done when the stage four processing option is selected. The stages of processing are explained in Section 2.4.

Another file of adjusted coordinates can be produced by selecting this option using column 56 of the option record. This file has the same format as the station records used for input to the program and has the extension '.stn'. There are several options available for the storage of data using this output file.

2.18 Error Ellipses

If error ellipses are required either after adjustment or for optimisation, the matrix of normal equations can be inverted. Elements of the inverse matrix will then be used for the calculation of relative or absolute error ellipses for all connected stations and for selected stations.

An option can also be selected to obtain point error ellipses for all stations in the adjustment.

As the amount of time taken to invert the matrix is quite large for large matrices, the inversion is optional and need only be calculated when error ellipses are required.

The matrix obtained after the calculation is the full inverse matrix so that error ellipses can be calculated for any pair of stations within the network. If both stations selected are unfixed, a relative ellipse is obtained. If one is fixed, an absolute ellipse for the unfixed station is obtained.

Orientation parameters are not included in the calculation of the inverse matrix to save processing time. An option is available to include these if required.

2.19 Station Information from External Files

When the station label format is being used, the program will search for station data in a variety of text files using the label as the station identifier. If required, the program can be run with an input file containing observation data only. The program will automatically try to open various files when it needs information for a station. For internal use, station data is often extracted from a file obtained from SCIMS. This is usually the CSV file output of a polygon search of the SCIMS database.

Information on the various file types used for station data is given in Section 3.1.4.4.

2.20 Automatic Omission of Stations

If observations to an unfixed station have been omitted from the input data, a zero term will occur on the diagonal of the normal matrix. This would cause the solution to fail. To prevent this happening, the program checks that every station in the adjustment appears in at least one observation.

This check is done before the formation of the normal equations. Stations that do not fulfill this requirement are excluded from the adjustment by the program and indicated as omitted in the station output.

A station is also excluded if the program is unable to calculate provisional coordinates for it. This exclusion will cause errors related to missing stations to occur during observation processing but will enable errors due to other causes to be detected.

A third reason for the exclusion of a station is the duplication of the number or label allocated to the station. The program uses its own internal sequential number for each station in the adjustment. The duplication of a number will result in the failure to link an observation to the

station with the duplicated number. A zero diagonal term in the normal matrix would occur in this situation.

2.21 Automatic Insertion of Stations

The program will automatically include in the adjustment any station shown in an observation but not found in the list of stations. If required this can be used for all stations so that only fixed stations need be entered in the station data section of the input. A station record would be required if station heights need to be entered.

When a station is inserted by the program, it places the number of the station in the name field after the word 'Station' and automatically computes the coordinates.

2.22 Check for Duplicated Station Labels

When the label format is used for station coordinate input, the program compares the label entered with the list of labels used for stations previously entered. If a label is found to have been already used the status of the coordinates is checked.

If stations with duplicated labels are indicated as unfixed in the adjustment, second and subsequent stations with the same label are ignored.

If stations with duplicated labels have a status different from the initial station a warning is shown in the station list. For example if the second occurrence of a station label is indicated as fixed when the first is indicated unfixed, a warning is shown in the station list and the second station is omitted from the adjustment.

If stations with duplicated labels are all indicated as fixed, the coordinate values are compared with the initial station and a warning is shown in the station list if they are different.

2.23 Eccentric Mark Height Differences

For supplementary adjustments, height difference observations between eccentric marks and between the main station and eccentric marks can be entered. These observations are used to verify the value entered for the eccentric height difference with the station information. The observations are not used in the adjustment.

If a difference of more than 10.0 millimetres occurs in the comparison of height data, an error message is printed.

2.24 Station Information Using Provisional Coordinates

If required, geographical coordinate information, station summaries and other station output can be obtained using provisional coordinate values. No adjustment is carried out when this option is selected.

This can be used to obtain approximate azimuths and distances between stations supplied in a list of stations without doing an adjustment. It can also be used to obtain azimuth and distance information after optimisation or to create a plot file, using provisional coordinates.

The option can be selected using column 42 of the option record.

2.25 Bearing and Distance Input

The entry of this type of data, which can be done using separate bearing and distance records, has been simplified by designing a specific record for this purpose. It has been included for coordinated cadastral applications so that the bearing and distance between two stations can be entered in one record.

When data is entered in this form, a blank field for either a distance or a bearing is assumed to indicate that it has the same value as the one previously entered. This frequently occurs in cadastral applications where parcel boundaries have the same bearing or distance values. A set of bearings can be entered using a bearing and distance record even if there are no distances to be entered.

The input of bearing and distance data can be used to group bearings into sets that are rotated in the adjustment. Each set of bearings will be associated with an orientation parameter that is corrected in the adjustment. This explained in Section 2.14.

2.26 Reduction of Distances

Distances entered can be specified as being slope or spatial distances, horizontal distances at the height of the occupied station, sea level distances, ellipsoidal arc distances or plane distances. The default distance type is sea level.

Slope and horizontal distances will be reduced to sea level or a required height datum using station heights supplied in station records.

The corrections applied to a slope distance are slope correction, height correction and chord-to-arc correction. Corrections applied to a horizontal distance are height correction and chord-to-arc correction.

An option is also available for the reduction of slope or sea level distances to the ellipsoid. This is computed using a geoid-ellipsoid separation model stored within the program. Column 36 of the option record can be used to select this option. Separation values can be entered using an input file if required or they can be entered in the station 'geo' record.

The type of distance can be specified by entering a character in column 49 of the '22' record, column 78 of the '25' record, column '64' of the 'dis' record or column 59 of the 'dds' record and the 'bds' record.

The characters that can be used and their meanings are shown in Section 3.1.2.11. Heights of instrument and reflector can also be entered in the '22' record and the 'dis' record.

If station heights needed for distance reduction have not been entered with the station data, a mean height of the network is used for either one or both stations. This is to allow for an iterative horizontal and vertical adjustment in which a provisional height might not be available for the first horizontal adjustment iteration.

A more approximate way of reducing ground distances to sea level is to apply a scale factor based on the average height of the network. The scale can be computed and entered in the option record in columns 72 to 76. If the character 'H' is entered in column 72 the program will compute a scale based on the average height of the network. The average is computed using all the height values entered with station information. When the 'H' option is used, the scale factor is not applied to slope, horizontal or ellipsoidal distances.

For transformation of ISG datasets to GDA94, a distance can be entered as an ISG projected value. This is converted to an ellipsoidal distance by computing the ISG scale factor and converting the distance to an ANS ellipsoidal distance. The ANS distance is then converted to a GRS80 ellipsoidal distance by interpolating values for the geoid-ellipsoid separation for both the ANS and GRS80 ellipsoid using the models contained in the program.

This type of data can be entered only if the ISG zone is entered in the option record. Therefore it must be used in conjunction with the option for transforming the data set to GDA94. The entry of a '9' in column 52 of the option record can be used to select this option.

A report on the distance reduction that is done by the program can be obtained by selecting the option in the option record. This shows intermediate values resulting from each step of the reduction. The option can be selected by entering '2' in column 32 of the '01' record or entering 'd' in the '02' record.

2.27 Auxiliary Parameters for Scale and Rotation

The program can solve for auxiliary parameters representing rotation unknowns for sets of bearings and scale unknowns for sets of distances. The rotation parameter option is activated by using the bearing and distance form of input described in Section 2.14.

Auxiliary parameters for scale can be included by defining sets of distance observations. This is done by indicating the start of a set in a distance record and, if necessary, indicating the end of a set. Distance sets can also be defined in the bearing and distance record. A scale parameter is included for each set of distances defined in the input data.

When auxiliary parameters are used, the bandwidth and the number of terms in the normal matrix can become large. If this occurs the solution and inversion of the matrix will take more time.

2.28 Geoid-Ellipsoid Separation Models

The program has stored within it two models representing the separation between the geoid and both the Australian National Spheroid and the GRS80 ellipsoid. These can be used to obtain the separation, N , for any station in the adjustment depending on the ellipsoid used. The value is obtained using the station coordinates.

If the option for reduction of distances to the ellipsoid is selected, the separation value is printed with the station information.

The models currently apply only to the polygon defined by the boundaries of New South Wales and have been obtained from the following sources. The ANS values are from those published in the Australian Geodetic Datum Technical Manual by the National Mapping Council of Australia in 1986.

The GRS80 model is based on the AUSGEOID09 values provided by Geoscience Australia in March 2011. A half degree grid is used in HAVOC to model the separation so differences of up to 30 centimetres from the full AUSGEOID09 model may be obtained.

2.29 Cartesian Coordinate Differences

Although this program is intended for two-dimensional adjustment of terrestrial observations, it will accept observed WGS84 or GRS80 cartesian coordinate differences. These are converted to either bearings and ellipsoidal distances or azimuths and spatial distances before the adjustment. The computation is done for each iteration of the adjustment so that any variation in the provisional coordinates will result in an updated azimuth and distance. The option is selected by entering either a '2' or '3' in column 38 of the option record.

This type of information can be used to supply scale and azimuth information for an adjustment consisting mainly of terrestrial observations.

For the conversion of three dimensional vectors, the height of the occupied station is required. A height value can be entered with other station information or computed using three dimensional vectors connecting the station to other stations. If a height value is not available when required the average height of the network is used. Because the adjustment is two-dimensional, the heights of all stations are regarded as fixed.

A standard deviation can be entered for both derived azimuth and distance observations. When an azimuth standard deviation is not entered, it is computed as the angle subtended by a line of the same length as the distance standard deviation perpendicular to the observed line. This will result in a standard deviation for the azimuth equivalent to the distance standard deviation. Centering standard deviation is disabled for this computed azimuth standard deviation.

2.30 Station Connection Information

To assist in the analysis of a large network adjustment, a file showing station connection information can be obtained. This file, which is now automatically produced, shows each station in the adjustment with the stations connected to it. A maximum of ten connected stations is shown because the objective of this analysis is to find stations with minimal connections resulting in weaknesses in the network.

Connections such as radiations, intersections and resections are identified in the output file. There is also an option for an additional report on stations not connected and within a specified distance. The file name of this output file has the extension '.con'.

2.31 GDA94 Transformation

If requested, the programs will transform ISG or AMG coordinates to MGA. This function can be used to convert existing datasets from either ISG or AMG to MGA. All station coordinates are transformed including fixed stations. A warning is shown in the station list when a fixed station is transformed because transformation should normally be used for provisional coordinates only.

The transformation method used depends on the location of the station. If it is in NSW, the transformation is done using multiple regression equations. If it is outside NSW, the national similarity transformation parameters for AGD84 are used. If it is south of 40 degrees, the Tasmanian similarity transformation parameters are used.

When the input data file contains both AGD and GDA coordinate values those which are not to be transformed can be indicated using the datum indicator "G" in the station record.

The transformation will be selected automatically if stations with coordinates in both the AGD and GDA datums are entered. The datum can be indicated using column 80 of the '10' records, '11' records and 'geo' records and column 82 of the 'grd' and 'stn' records.

To select the transformation option the number '9' should be entered in column 52 of the '01' record or a 'T' entered in the '02' record. The ISG or AMG zone of the input coordinates must be entered in the option record. The program will determine the MGA zone.

2.32 Transformation of ISG Data

An input file containing ISG coordinates and ISG bearing and distance data can be converted to MGA by selecting the GDA94 transformation option and indicating that the observations are ISG. An 'I' is entered in the observation record to indicate this.

The program converts the ISG bearings and, distances if required, to geodetic azimuths and ellipsoidal distances. It does this by computing the ISG grid convergence and line scale factor for each line. These values are applied to the input values to obtain ANS azimuths and ANS ellipsoidal distances. The distances are converted to GRS80 ellipsoidal distances using the geoid-ellipsoid separation models. The adjustment is then done using the ellipsoidal values.

The ellipsoidal observations can be output in a separate file if required and used as program input with other data. This can be done by entering a '4' in column 50 of the option record or an 'a' in the '02' record.

2.33 Adjustment of DP Data

An option is available for extra processing required for the adjustment of data entered in a spreadsheet from Deposited Plans. When this option is selected the program will check for and, if required, reformat tab-separated data to create a new correctly formatted input file. This is to allow the processing of data exported from a spreadsheet.

Duplicated observations are also found and written to a file with an extension '.dup'. Duplicated observations are not included in the revised input file.

The revised input file name will have the extension '.hav'. If the original input file name has the same extension the original file will be copied into a file with the extension '.cpy'. This ensures that the original data is not lost.

2.34 Output of Network Plot File

A file suitable for input to the TCL/TK plotting program is always produced. This file contains station coordinates and observation coordinates that can be used to display the network on the screen or plot it on paper. The file has the extension '.spd'.

3. INPUT AND OUTPUT

There are many processing options provided by HAVOC. Because of the number of options available, the program accepts a variety of data as input and produces a wide variety of output. Input and output functions of the program are described in this section.

3.1 Input

3.1.1 Method of Input

Input to the program was originally by punched cards. Input is now by means of a text file. The older format of this file is the same as the format of the cards that were read by the original program. When the program is run the default extension of the input file is '.hav'.

Two formats of input file are available. In the older format a number is used for the station identifier. The station number is used in the station and observation records to link the observations with the stations.

Another format, in which a character string of up to 12 characters can be used as the station identifier, was developed in 1996. When this format is used, station and observation records must include station labels.

A record type is used to identify each record of the input file. For the station number format this is indicated using the first two columns of the record. For the station label format the first three columns are used.

The first record must be a '92' record, if this type of record is required. For the station number format subsequent records must be entered in ascending numerical order. If the first two columns of the record are blank, or contain characters not recognized by the program, the record is ignored.

The only exception to the ordering of records is the '95' record which can be interspersed with records of all types. The program checks the order of records as they are read. If a record is out of order an error message is printed and the record is ignored.

When the station label format is used, records after the '92' and the '01' records can be entered in any order. The program sorts them as they are read.

A correctly formatted file can be created using a general purpose text editing program. Alternatively a program specifically designed for data entry could be used to enter data.

3.1.2 Station Number Format

3.1.2.1 Adjustment Description Record (92)

Column 1-2 Record Type = 92

Column 3-70 Adjustment description of up to 68 characters

There may be either 1 or 2 of these records if a heading is required, and they must be the first records in the file. The text entered in this record will be included in the heading on each page of the output file. This record can be omitted if a heading of this type is not required in the output file.

3.1.2.2 Comment Record (95)

Column 1-2 Record Type = 95

Column 3-80 Text

The program ignores a record of this type. It can be used to insert comments in the data if required. To temporarily remove a record of any type from the adjustment, the record type can be changed to '95' instead of deleting the entire record.

This record type has been superseded in later versions of the program because of changes to the file reading process. The same result can now be obtained by changing the first two columns to spaces. Any number of lines of text can be inserted in the input data provided the first two columns are not recognized by the program.

3.1.2.3 Option Record (01)

If an option record is not included in the input file or is not available in the file 'havoc.opt', default options will be used by the program. Default options do not include a zone value. If geographical coordinates are read by the program the zone will be determined from the first values read.

Column 1-2 Record Type = 01

Column 3 The character 'X' or 'x' can be entered to indicate that options contained in the option file are to be ignored.

Column 4-6 Zone number of the grid used for the adjustment. For geocentric systems a prefix is included to identify the ellipsoid. This field can be left blank if station data is read from a SCIMS file. The zone is read from the SCIMS file and assumed to be MGA.

In later versions of the program the zone is assumed to be MGA. To select an AMG zone the prefix '6' or '0' can be used.

If the zone is not entered, and the program reads geographical coordinate input values, the zone will be computed using the first longitude value read.

The zone value must be in the range

10 - 60 for MGA/GDA94
542 - 572 for ISG
649 – 657 for AMG/AGD66
701 - 760 for WGS72
801 - 860 for MGA/GDA94

These columns should be left blank for an adjustment on a local grid.

Column 8 Request for suppression of arc-to-chord and line scale factor reductions. If no reductions are required, enter the character 'N'. By default these reductions are applied.

Column 10 Enter 'S' for supplementary adjustment. .

The character 'C' can be used to request that station information for all stations should be sought in external files. The external files accessed are described in Section 3.1.4.4.

The character 'F' can be entered to request that information for stations indicated as fixed only is accessed in external files.

The character 'U' can be entered to request that information for stations indicated as unfixed only is accessed in external files.

The character 'N' can be entered to request that no access to external files is required.

Column 11 The character 'D' can be entered to indicate that DP data from a spreadsheet is being processed. For this type of data the program interprets tab or comma separated fields and removes duplicate observations.

The character 'B' can be entered to bypass the matrix de-banding process. This will maintain the input order of stations in various output files.

Column 12-15 Limit in minutes of arc for the difference between the computed and observed values of a direction or azimuth observation. Default value is 25 minutes. Maximum is 9999 minutes.

Column 16-18 Limit in metres for the difference between the computed and observed values of a distance observation. Default value is 10. Maximum is 400.

Column 20-23	This field can be used to enter a value in kilometres for the selection of unconnected stations for a connection report or for error ellipses.
Column 25-26	The character '4' can be entered to obtain a report and, if required, error ellipses for unconnected stations using the distance value in the field above.
Column 28	Number of decimal places for direction or distance output. For directions the minimum is 1 and maximum is 3. The default is 1. For distances the number 4 can be entered to obtain 4 decimal places. The default is 3. When 4 decimal places for distances are selected, 3 are used for directions.
Column 29	A number entered in this column is used to select the largest order required for stations from a SCIMS file to be held fixed in the adjustment. The default value is 2.
Column 30	A numerical character can be entered to suppress provisional coordinate computation output showing how each station is coordinated.
Column 32	The character '1' can be entered to obtain observation equation output. The character '2' can be entered to obtain a report on distance reduction.
Column 34	The character '1' can be entered to obtain the solution of the normal matrix. The character '2' can be entered to obtain an APX file for GEOLAB. When this option is selected a file of direction observations and spatial distance observations formatted for GEOLAB is produced. This file has the extension '.cob'. The station file has the extension '.apx'. The character '3' can be entered to select the output of ellipsoidal distances.
Column 36	The character '1' can be entered to request that a geoid-ellipsoid separation value, N, be interpolated from the internal model and applied to the orthometric heights for the reduction of distances to the ellipsoid. If required a more accurate value of N can be entered with the input data in 'geo' records or in the file described in Section 3.1.4.3. If distances are entered as sea level values or scaled for reduction to sea level the N values will be used for reduction to the ellipsoid. The character '2' can be entered to indicate that all height values entered are ellipsoidal. In this case geoid-ellipsoid separation values will not be applied.

- Column 38 The character '2' can be entered to request that cartesian coordinate differences be converted to bearings and ellipsoidal distances. This is the default.
- The character '3' can be entered to request that cartesian coordinate differences be converted to azimuths and spatial distances.
- The character '4' can be entered to obtain a report on the cartesian coordinate computation used by the program. When this option is selected the option '2' is used for processing.
- Column 40 A numerical character can be entered to suppress stage one observation output. This can be used to reduce the size of the output file for an adjustment. Error messages related to the observations will be printed.
- Column 42 A numerical character can be entered to obtain final station information derived from provisional coordinate values without adjustment or after optimisation. This option is ignored if error ellipse output after adjustment is requested using column 64.
- Column 44 The character '2' can be entered to request that distance observations between fixed stations should be omitted from the adjustment and direction observations between fixed stations should be indicated.
- The character '3' can be entered to request that stations used for orientation be automatically held fixed so that an unconstrained adjustment can be done.
- Column 46 A numerical character can be entered to obtain an adjusted coordinate list in the format that was used for mapping control projects. This is ignored for stage 4 adjustments.
- Column 48 The character '1' can be entered to obtain a station summary for each station in the adjustment.
- The character '2' can be entered to obtain station summaries showing additional information related to the azimuth and distance between stations. This option can also be used to obtain ISG station summaries.
- The character '3' can be entered for the reduction of distances to the mean height of the two connected stations in the station summary.
- Column 50 The character '1' can be entered to obtain a stage four coordinate file formatted for use by other programs. This file has the prefix 'i' and the extension '.dat'.
- The character '2' can be entered to obtain a station coordinate file formatted for CIVILCAD. The file has the extension '.civ'.

The character '3' can be entered to obtain a station coordinate file formatted for MINICAD. The file has the extension '.min'.

The character '4' can be entered to obtain a file of azimuth observations derived from GPS baselines or azimuth and distance observations derived from ISG bearings. An azimuth file has the extension '.azm'. An azimuth and distance file has the extension '.ads'.

The character '6' can be entered to request the conversion of a label input file to a number input file. The file has the extension '.num'.

Column 52

The character '8' can be entered in this column to request that ISG coordinates in stations records be converted to AMG coordinates which will then be used for the adjustment.

The character '9' can be entered to request that coordinates entered in station records be transformed from either ISG or AMG66 to MGA94. When this option is selected the ISG or AMG zone should be entered in the options record.

Column 54

Stage of processing required. Default value is 2.

- 1 data checking phase
- 2 adjustment
- 3 adjustment with output of geographical information
- 4 creation of a file of adjusted coordinate values after adjustment

Column 56

The character '1' can be entered to obtain a file of station information both before and after the adjustment showing grid coordinates.

The character '2' can be entered to obtain a file with geographical coordinates.

This file is named using the input file name with the extension '.stn' and has the same format as the station records used as input for an adjustment.

If the character '3' is entered the station file created is inserted in the input file. The original file is saved with the extension '.cpy'.

If the character '4' is entered, coordinates for fixed stations only are included the input file.

Column 58

Number of iterations required for the adjustment. Default value is 1.

Column 60-62

Factor used to modify direction standard deviations entered. All values entered are multiplied by this factor.

Column 63

The character 'F' can be entered to obtain the inversion of the full normal matrix. Normally the orientation parameter columns are omitted.

Column 64	<p>Precision analysis processing required. If the calculation of error ellipses is requested the normal matrix has to be inverted. For large networks this will increase the processing time.</p> <p>Blank adjustment only.</p> <ol style="list-style-type: none"> 1 relative error ellipses after adjustment. 2 relative and point ellipses after adjustment. 3 error ellipses with normal and inverse matrix printed. 4 optimisation. 5 optimisation with normal and inverse matrix printed.
Column 66	<p>The character '1' can be entered to select the scaling of the error ellipse values by the adjustment variance factor. The default scaling factor is 1.0.</p> <p>The character '2' can be entered if error ellipses for all observations are not required. In this case only error ellipses selected will be produced.</p> <p>The character '3' can be entered to obtain a file of relative error ellipse values for the analysis of class. The file will have the extension '.cls'.</p> <p>The character '4' can be used to select the scaling of the error ellipse values by the variance factor and also to obtain a file of ellipse values scaled by the variance factor.</p>
Column 68-71	<p>Centering standard deviation in centimetres. This value represents the combined centering standard deviation for both ends of the line. It is applied to the standard deviations of all azimuth, bearing and direction observations except where requested in the observation record.</p>
Column 72-76	<p>Factor used to reduce all observed distances before processing. The value is in the form of parts per million and can be used for a scale correction to all distances to allow for geoid-ellipsoid separation. It can also be used to enter a scale correction to be applied to all distances for reduction to sea level. If H represents the average height of the network, a scale value can be calculated using the formula $S = H/6.370$.</p> <p>The character 'H' or 'h' can be placed in column 72 to request that the average height of the network be used by the program to calculate a scale factor for reduction of distances to sea level. The scale factor determined using the 'h' character will not be applied to slope, horizontal or ellipsoidal distances.</p>
Column 77-79	<p>A variance factor test value can be entered to limit the adjustment to stage two if the value is exceeded. Default value is 5.0.</p>
Column 80	<p>The character '2' can be entered to obtain an adjustment report file with the extension '.rpt'. In the current version this is automatically set. To suppress the report the character '0' can be entered.</p>

The character '3' can be entered to obtain both the adjustment report and an extract of the adjustment output file with an 80 column format. The name of this file has the extension '.ext'.

3.1.2.4 Option Record (02)

An alternative option record can be used to select commonly used options. This record is column independent and free format and so can be easier to use for standard adjustments.

This option record is free format with items separated by spaces. The characters used to select options can be in any position and in any order in the record. Upper case letters are used for processing options and lower case letters are used for output options. The order used below is for description of the options and does not imply any order in the record.

Only options to be selected need be entered.

Item	Entry example
Zone	56
Datum (Default GDA)	AGD
C-O limits	L350,100
Type of adjustment data	
Supplementary.	D1
DP.	D2
Station data from files	S
Transformation from AGD66 to GDA94	T
Processing	
Compute coordinates and (c-o) values	1
Compute coordinates and adjustment.	2
Compute coordinates, adjustment and geographical coordinates.	3
Compute coordinates, adjustment and produce stage 4 output file	4
Compute coordinates, adjustment, geographical coordinates and station summaries	6
Compute coordinates, adjustment, geographical coordinates and extended station summaries.	7
Compute coordinates and produce station information without adjustment.	8
Number of iterations	I3

Centering.	C0.5
Scale Factor	S2.5
Scale factor using station heights	H
Use N value to reduce distances to ellipsoid	N
Remove distances between fixed stations	F
Fix radiated stations to run unconstrained adjustment	F1
Largest order for station in SCIMS file to be fixed.	O3
Conversion option for GPS baselines.	G2
Station Information Output	
Station file in input format, '.stn'	s
Coordinate file, '.crd'	s1
Coordinate file, '.dat'	s2
'crd' file and 'stn' file	s3
Copy station file into input file	s4
Copy only fixed station into input file	s5
Error ellipses	
Output of relative and point error ellipses	e
Output of relative ellipses only	e1
Output of ellipses scaled by variance factor	e2
Output of only selected relative error ellipses	e3
Other Output	
Report on distance reductions	d
Azimuth file	a
Report on unconnected stations	u1.0
GEOLAB station, '.apx', and observation output, 'cob'	g
Output of file of Class information based on error ellipses	c

Example

Options can be in any order and in any column. Upper and lower case letters have specific meanings and should be used as indicated above.

```
02 56 4 I4 L350,100 e C0.5 S2.5 c
```

An equivalent record to the above would be

3.1.2.5 Station Record (10)

If station information is not entered the program searches for it in a file with a name based on the input file name with the extension '.stn' if this is available. The format of this file should be the same as the '10' record shown below.

Column 1-2	Record Type = 10
Column 4-6	Station number. The number can be in the range 1 to 999.
Column 7	Station status. Blank for an unfixed station. '-' or '*' for a fixed station.
Column 8-18	Easting coordinate. If coordinate fields are blank, coordinates will be computed by the program.
Column 19-29	Northing coordinate.
Column 31-50	Station name - up to 20 characters.
Column 52-56	SCIMS number.
Column 58	Eccentric mark number for supplementary adjustments. A '0' can be entered to indicate the main station. For non-supplementary adjustments the letter 'E' can be entered to indicate that the station height entered is an ellipsoidal value.
Column 59-66	Station height in metres. Default height type is orthometric. (Optional. See Section 2.2.5) For supplementary adjustments the value to be entered is the eccentric height difference.
Column 68-72	Standard deviation for easting in metres. (Optional. See Section 2.2.7)
Column 74-78	Standard deviation for northing in metres. (Optional. See Section 2.2.7)
Column 80	Coordinate datum. 'G' indicates GDA and 'A' indicates AGD. A character entered remains the default until changed. The datum can also be selected using the option record.

3.1.2.6 Station Record (11)

Geographical coordinates entered using this record are converted to grid coordinates before being used.

Column 1-2	Record type = 11
Column 4-6	Station number for adjustment.
Column 7	Station status. Blank for an unfixed station. '-' or '*' for a fixed station.
Column 8	Latitude sign. '-' or 'S' for southern latitudes.
Column 9-10	Station latitude - degrees.
Column 11-12	Station latitude - minutes.
Column 13-20	Station latitude - seconds.
Column 21	Longitude sign. '-' or 'W' for western longitudes.
Column 22-24	Station longitude - degrees.
Column 25-26	Station longitude - minutes.
Column 27-34	Station longitude - seconds.
Column 36-55	Station name - up to 20 characters.
Column 58	The letter 'E' can be entered to indicate that the station height entered is an ellipsoidal value.
Column 59-66	Station height in metres. Default height type is orthometric. (Optional. See Section 2.2.5)
Column 68-72	Standard deviation for easting in metres. (Optional. See Section 2.2.7)
Column 74-78	Standard deviation for northing in metres. (Optional. See Section 2.2.7)
Column 80	Coordinate datum used. 'G' indicates GDA94 and 'A' indicates AGD66. A character entered remains the default until changed. The datum can also be selected using the option record.

3.1.2.8 Laplace Observation Record (19)

Column 1-2	Record type = 19
Column 4-7	Occupied station number.
Column 9-11	Observed station number.

Column 13-15	Astronomic azimuth - degrees.
Column 16-17	Astronomic azimuth - minutes.
Column 18-23	Astronomic azimuth - seconds.
Column 25-30	Standard deviation of azimuth in seconds.
Column 32-34	Astronomic longitude - degrees.
Column 35-36	Astronomic longitude - minutes.
Column 37-42	Astronomic longitude - seconds.
Column 45-47	Astronomic latitude - degrees.
Column 48-49	Astronomic latitude - minutes.
Column 50-55	Astronomic latitude - seconds.
Column 58-60	Elevation angle - degrees. This will be computed from station heights if they have been entered.
Column 61-62	Elevation angle - minutes.
Column 63-68	Elevation angle - seconds.
Column 70	Occupied eccentric number.
Column 72	Observed eccentric number.

3.1.2.9 Azimuth or Bearing Record (20)

Column 1-2	Record type = 20
Column 4-7	Occupied station number.
Column 9-11	Observed station number.
Column 12	Azimuth indicator. If the character 'A' is entered the value entered is treated as an azimuth and grid convergence and arc-to-chord corrections are applied. If blank a bearing value is assumed. The character 'I' can be entered to indicate that the value entered is an ISG plane bearing. This is converted to an azimuth before processing.

To indicate the end of a group of records with a default 'I' indicator the character 'B' can be entered.

Column 13-15	Bearing - degrees.
Column 16-17	Bearing - minutes.
Column 18-23	Bearing - seconds.
Column 25-30	Standard deviation of bearing in seconds. This can be entered as a negative value to suppress the application of the centering standard deviation. The default value is 1.0 seconds.
Column 36	Occupied eccentric mark number.
Column 38	Observed eccentric mark number.

3.1.2.10 Observed Direction Record (21)

Column 1-2	Record type = 21
Column 3-7	Occupied station number. If two, three or more sets of directions from the same station are to be entered, add 1000, 2000 up to 19000 to the station number for each set after the first. The sets must be in numerical order.
Column 9-11	Observed station number.
Column 13-15	Observed direction - degrees.
Column 16-17	Observed direction - minutes.
Column 18-23	Observed direction - seconds.
Column 25-30	Standard deviation of observation in seconds. This can be entered as a negative value to suppress the application of the centering standard deviation. The default value is 1.0 seconds.
Column 36	Occupied eccentric mark number.
Column 38	Observed eccentric mark number.
Column 40-41	For versions of the program which are able to read more than 999 stations the set number can be entered in these columns.

3.1.2.11 Observed Distance Record (22)

Column 1-2	Record type = 22
Column 4-7	Occupied station number.

Column 9-11	Observed station number.
Column 13-23	Observed distance.
Column 25-28	Standard deviation in centimetres (constant). The default value is 10.0 centimetres.
Column 30-33	Standard deviation (parts per million). The default value is 0.0 ppm.
Column 36	Occupied eccentric mark number.
Column 38	Observed eccentric mark number.
Column 40	'S' indicates the start of a set of distances to which a scale parameter is allocated. 'E' indicates the end of a set of distances. This is implied by the start of a new set.
Column 42-47	Provisional value of the scale parameter in parts per million. It is read only from the first record of the set of distances.
Column 49	Type of distance indicator. Distances are converted to mean sea level and then to the ellipsoid if requested. (See Section 2.27)
	'S' indicates a slope or spatial distance.
	'H' indicates a horizontal distance at the height of the occupied station.
	'G' indicates a geoidal or mean sea level distance. This is the default type.
	'E' indicates an ellipsoidal distance.
	'P' indicates a plane distance.
	'I' indicates an ISG projected distance.
	'X' requests the conversion of a sea level distance or an ellipsoidal distance to a slope or spatial distance.
Column 50	The character 'H' in this column is interpreted in the same way as the character 'S' in column 49. This is to allow processing of HAVOC Version 2.2 datasets.
Column 52-58	Height datum value in metres for the reduction of the observed distance. For reduction to sea level this will be blank.
Column 60-66	Height of instrument.
Column 68-74	Height of target.

3.1.2.12 Height Difference Record (24)

These height differences are used only for supplementary adjustments as a check on eccentric height connections.

Column 1-2	Record type = 24
Column 4-6	Occupied station number.
Column 9-11	Observed station number.
Column 13-21	Height difference.

3.1.2.13 Bearing and Distance Record (25)

Column 1-2	Record type = 25
Column 3	'S' indicates the start of a bearing set. 'E' indicates the end of a bearing set. This is implied by the start of a new set.
Column 4-7	Occupied station number.
Column 9-11	Observed station number.
Column 12	<p>Azimuth indicator. If the character 'A' is entered the value is treated as an azimuth and grid convergence and arc-to-chord correction are applied. The character 'I' can be entered to indicate that the value is an ISG plane bearing. This is converted to an azimuth before processing.</p> <p>To indicate the end of a group of records with a default 'I' indicator the character 'B' can be entered.</p>
Column 13-15	Azimuth or bearing - degrees.
Column 16-17	Azimuth or bearing - minutes.
Column 18-23	<p>Azimuth or bearing - seconds.</p> <p>If left blank the previous azimuth value will be used.</p>
Column 25-28	Standard deviation of azimuth or bearing. This can be entered as a negative value to suppress the application of the centering standard deviation. The default values is 1.0 seconds.
Column 30-40	<p>Distance.</p> <p>If left blank the previous distance value will be used. If there is no distance available a negative value can be entered to indicate this.</p>
Column 42-45	Standard deviation in centimetres (constant). The default value is 10.0 centimetres.
Column 47-50	Standard deviation (parts per million). The default value is 0.0 ppm.

Column 52-54	Provisional set orientation - degrees.
Column 55-56	Provisional set orientation - minutes.
Column 57-62	Provisional set orientation - seconds.
Column 64	'S' indicates the start of a set of distances to which a scale parameter is allocated. (Usage is as shown in '22' record format description).
Column 66-71	Provisional value of the scale parameter in parts per million.
Column 72-77	Height datum value in metres for reduction of the observed distance.
Column 78	Type of distance indicator. (Usage is as shown in the '22' record format description).

3.1.2.14 Cartesian Coordinate Difference Record (26)

Column 1-2	Record type = 26
Column 3	'S' indicates the start of a set of derived bearings. 'E' indicates the end of a set.
Column 4-7	Number of 'from' station.
Column 9-11	Number of 'to' station.
Column 12-22	X coordinate difference.
Column 23-33	Y coordinate difference.
Column 34-44	Z coordinate difference.
Column 46-49	Standard deviation for derived bearing. The default value is computed as the angle subtended by the distance standard deviation.
Column 51-54	Constant part of standard deviation for derived distance. The default value is 0.5 centimetres.
Column 56-59	Parts per million part of standard deviation for derived distance. The default value is 2.0 ppm.
Column 65	'S' indicates the start of a set of derived distances. 'E' indicates the end of a set. (Usage is as shown in '22' record format description).
Column 66-70	Height of instrument at 'from' station
Column 72-76	Height of instrument at 'to' station

Column 78 Eccentric mark used at 'from' station.

Column 80 Eccentric mark used at 'to' station.

3.1.2.15 Selected Error Ellipse Record (50)

Column 1-2 Record type = 50

Column 4-7 From station number.

Column 9-11 To station number. If the value -9 is entered in this field, error ellipses between all stations and the same 'from' station will be selected.

3.1.2.16 End of Data Record

This record used to be required to indicate the end of a data set. For later versions of the program it is not essential. For the G77 versions of the program it is essential that the last data record be terminated with a carriage control. If not the record will be ignored.

Column 1-2 Record type = 99

3.1.3 Station Label Format

An input format in which a 12 character station label can be used as the station identifier is available. This label is shown in both station and observation records instead of the number used for the station identifier in the older format. The program automatically detects the format used for the data.

The '92' and '01' records are the same for both formats.

When this format is used observation and station record types can be mixed so that distance records can be located adjacent to relevant direction or azimuth records if required.

Records entered using this format can include comments preceded by the character '!'. Any text following this symbol is ignored.

3.1.3.1 Station Record (Grid Coordinates)

If station information is not entered the program searches for it in external files if they are available. This process is explained in Section 3.1.4.4.

Column 1-3 Record Type = 'grd' or 'stn'

Column 4 Station status. Blank for an unfixed station. '-' or '*' for a fixed station.

Column 5-16	Station label.
Column 18-37	Station name.
Column 38-48	Easting coordinate. If coordinate fields are blank, coordinates will be sought in station data files or computed by the program.
Column 49-59	Northing coordinate.
Column 60	The letter 'E' can be entered to indicate that the station height entered is an ellipsoidal value.
Column 61-68	Station height in metres. Default height type is orthometric. (Optional. See Section 2.2.5)
Column 70-74	Standard deviation for easting in metres. (Optional. See Section 2.2.7)
Column 76-80	Standard deviation for northing in metres. (Optional. See Section 2.2.7)
Column 82	Coordinate datum. 'G' indicates GDA94 and 'A' indicates AGD. A character entered remains the default until changed. If any other character is entered it is regarded as a blank character. The datum can also be selected using the option record.

3.1.3.2 Station Record (Geographical Coordinates)

Coordinates entered using this record are converted to grid values before being used.

Column 1-3	Record type = 'geo'
Column 4	Station status (as in 'grd' records).
Column 5-16	Station label.
Column 18-37	Station name.
Column 38	Latitude sign. '-' or 'S' for southern latitudes.
Column 39-40	Station latitude - degrees.
Column 42-43	Station latitude - minutes.
Column 45-52	Station latitude - seconds.
Column 53	Longitude sign. '-' or 'W' for western longitudes.
Column 54-56	Station longitude - degrees.
Column 58-59	Station longitude - minutes.

Column 61-68	Station longitude - seconds.
Column 70	The letter 'E' can be entered to indicate that the station height entered is an ellipsoidal value.
Column 71-78	Station height in metres. Default height type is orthometric. (Optional. See Section 2.2.5)
Column 80	Coordinate datum. 'G' indicates GDA and 'A' indicates AGD. A character entered remains the default until changed. If any other character is entered it is regarded as a blank character. The datum can also be selected using the option record.
Column 81-85	Standard deviation for easting in metres.
Column 87-91	Standard deviation for northing in metres.
Column 99-105	Geoid-ellipsoid separation in metres.
OR	
Column 80	'\ ' indicates the presence of a continuation record.
Column 1	Coordinate datum. 'G' indicates GDA and 'A' indicates AGD. A character entered remains the default until changed. If any other character is entered it is regarded as a blank character. The datum can also be selected using the option record.
Column 3-7	Standard deviation for easting in metres.
Column 9-13	Standard deviation for northing in metres.
Column 21-27	Geoid-ellipsoid separation in metres.

3.1.3.4 Laplace Observation Record

Column 1-3	Record type = 'lap' or 'la '
Column 5-16	Occupied station label.
Column 19-30	Observed station label.
Column 32-34	Astronomic azimuth - degrees.
Column 36-37	Astronomic azimuth - minutes.
Column 39-44	Astronomic azimuth - seconds.

Column 46-51	Standard deviation of azimuth in seconds.
Column 53-55	Astronomic longitude - degrees.
Column 57-58	Astronomic longitude - minutes.
Column 60-65	Astronomic longitude - seconds.
Column 67-69	Astronomic latitude - degrees.
Column 71-72	Astronomic latitude - minutes.
Column 74-79	Astronomic latitude - seconds.

3.1.3.5 Azimuth or Bearing Record

Column 1-3	Record type = 'azm' , 'brg' 'az ' or 'br '
Column 5-16	Occupied station label.
Column 19-30	Observed station label.
Column 32	The character 'I' can be entered to indicate that the value entered is an ISG plane bearing. This is converted to an azimuth before processing. To indicate the end of a group of records with a default 'I' indicator the character 'B' can be entered in the first record that does not belong to previous group.
Column 33-35	Bearing - degrees.
Column 36-37	Bearing - minutes.
Column 38-43	Bearing - seconds.
	OR
Column 37-38	Bearing - minutes
Column 40-43	Bearing – seconds
	OR
Column 33-43	Bearing in HP format. (DDD.MMSSSSS)
Column 45-50	Standard deviation of bearing in seconds. This can be entered as a negative value to suppress the application of the centering standard deviation. The default value is 1.0 seconds.

Column 56	Occupied eccentric mark number.
Column 58	Observed eccentric mark number.

3.1.3.6 Observed Direction Record

Column 1-3	Record type = 'dir' or 'dr '
Column 5-16	Occupied station label.
Column 19-30	Observed station label.
Column 32	New set indicator. A character such as 'A', 'B' can be entered to group directions into sets. The character need be entered only on the first direction of the set. A new set is defined by a change of character so characters can be re-used if required. An alternative way of indicating a new set is to enter the character 'S' to indicate the first direction of a set.
Column 33-35	Observed direction - degrees.
Column 36-37	Observed direction - minutes.
Column 38-43	Observed direction - seconds.
	OR
Column 37-38	Observed direction - minutes
Column 40-43	Observed direction – seconds
	OR
Column 33-43	Observed direction in HP format. (DDD.MMSSSSS)
Column 45-50	Standard deviation of observation in seconds. This can be entered as a negative value to suppress the application of the centering standard deviation. The default value is 1.0 seconds.
Column 56	Occupied eccentric mark number.
Column 58	Observed eccentric mark number.

3.1.3.7 Observed Distance Record

Column 1-3	Record type = 'dis' or 'ds '
------------	------------------------------

Column 5-16	Occupied station label.
Column 19-30	Observed station label.
Column 33-43	Observed distance.
Column 45-48	Standard deviation in centimetres (constant). The default value is 10.0 centimetres.
Column 50-53	Standard deviation (parts per million). The default value is 0.0 ppm.
Column 55	'S' indicates the start of a set of distances to which a scale parameter is allocated. 'E' indicates the end of a set of distances. This is implied by the start of a new set.
Column 57-62	Provisional value of the scale parameter in parts per million. It is read only from the first record of the set of distances.
Column 64	Type of distance indicator. Distances are converted to mean sea level and then to the ellipsoid if requested. (see Section 2.27)
	'S' indicates a slope or spatial distance.
	'H' indicates a horizontal distance at the height of the occupied station.
	'G' indicates a geoidal or mean sea level distance. This is the default type.
	'E' indicates an ellipsoidal distance.
	'P' indicates a plane distance.
	'T' indicates an ISG projected distance.
	'X' requests the conversion of a sea level distance or an ellipsoidal distance to a spatial distance.
Column 66-72	Height of instrument.
Column 74-80	Height of target.

3.1.3.8 Direction and Distance Record

Column 1-3	Record type = 'dds' or 'dd'
Column 5-16	Occupied station label.
Column 19-30	Observed station label.
Column 32	New set indicator. A character such as 'A', 'B' can be entered to group directions into sets. The character need be entered only on the first direction of the set. A new set is defined by a change of character so

characters can be re-used if required. An alternative way of indicating a new set is to enter the character 'S' to indicate the first direction of a set.

Column 33-35 Observed direction - degrees.

Column 36-37 Observed direction - minutes.

Column 38-43 Observed direction - seconds.

OR

Column 37-38 Observed direction - minutes.

Column 40-43 Observed direction - seconds.

OR

Column 33-43 Observed direction in HP format. (DDD.MMSSSSS)

If there is an observed distance with no observed direction this field can be left blank.

Column 45-48 Standard deviation of direction. This can be entered as a negative value to suppress the application of the centering standard deviation. The default value is 1.0 seconds.

Column 50-58 Distance. If there is no distance this field can be left blank.

Column 59 Type of distance indicator as in distance record.

Column 60-63 Standard deviation in centimetres (constant). The default value is 10.0 centimetres. This information is read only when the distance value is not blank.

Column 65-68 Standard deviation (parts per million). The default value is 0.0 ppm.

Column 70 Distance set indicator. An 'S' can be entered to indicate the start of a set of distances to which a scale parameter can be allocated.

Column 72-77 Provisional value of the scale parameter in parts per million. It is read only from the first record of the set of distances.

3.1.3.9 Bearing and Distance Record

Column 1-3 Record type = 'bds' or 'bd '

Column 4 'S' indicates the start of a bearing set.
'D' indicates the start of a distance set.
'B' indicates the start of a distance and bearing set.

'E' indicates the end of a bearing set.
 'F' indicates the end of a distance set.
 'G' indicates the end of a bearing and distance set. This is implied by the start of a new set.

Column 5-16 Occupied station label.

Column 19-30 Observed station label.

Column 32 The character 'I' can be entered to indicate that the value entered is an ISG plane bearing. This is converted to an azimuth before processing.

To indicate the end of a group of records with a default 'I' indicator the character 'B' can be entered to indicate the beginning of a different type of azimuth.

Column 33-35 Bearing - degrees.

Column 36-37 Bearing - minutes.

Column 38-43 Bearing - seconds.

OR

Column 37-38 Bearing - minutes.

Column 40-43 Bearing - seconds.

OR

Column 33-43 Bearing in HP format. (DDD.MMSSSSS)

If left blank the previous bearing value will be used.

Column 45-48 Standard deviation of bearing. This can be entered as a negative value to suppress the application of the centering standard deviation. The default value is 1.0 seconds.

Column 50-58 Distance.

If left blank the previous distance value will be used. If there is no distance available a negative value can be entered to indicate this. The entry of the characters 'NA' or 'na' can also be used to indicate that there is no distance available.

Column 59 Type of distance indicator as in distance record.

Column 60-63 Standard deviation in centimetres (constant). The default value is 10.0 centimetres.

Column 65-68	Standard deviation (parts per million). The default value is 0.0 ppm.
Column 70-72	Provisional set orientation - degrees.
Column 73-74	Provisional set orientation - minutes.
Column 75-79	Provisional set orientation - seconds.
Column 81-84	Centering standard deviation for the bearings of this set in centimetres.
Column 86-91	Provisional value of scale parameter.

3.1.3.10 Azimuth and Distance Record

Column 1-3 Record type = 'ads' or 'ad '

The format of this record is the same as the 'bds' record shown above.

3.1.3.11 Cartesian Coordinate Difference Record

Column 1-3 Record type = 'ccd' or 'cd '

Column 4 'S' indicates the start of a set of derived azimuths. 'E' indicates the end of a set.

Column 5-16 Label of 'from' station.

Column 19-30 Label of 'to' station.

Column 32-42 X coordinate difference.

Column 43-53 Y coordinate difference.

Column 54-64 Z coordinate difference.

Column 66-69 Standard deviation for derived bearing. The default value is computed as the angle subtended by the distance standard deviation.

Column 71-74 Constant part of standard deviation for derived distance. The default value is 0.5 centimetres.

Column 76-79 Parts per million part of standard deviation for derived distance. The default value is 2.0 ppm.

Column 80 'S' indicates the start of a set of derived distances. '\ ' indicates the presence of a continuation record.

Continuation Record

Column 6	'S' indicates the start of a set of derived distances. 'E' indicates the end of a set. (Usage is as shown in '22' record format description).
Column 8-12	Height of instrument at 'from' station
Column 14-18	Height of instrument at 'to' station
Column 20	Eccentric mark used at 'from' station.
Column 22	Eccentric mark used at 'to' station.

3.1.3.12 Height Difference Record

These height differences are used only for supplementary adjustments as a check on eccentric height connections.

Column 1-3	Record type = 'dif'
Column 5-16	Occupied station label.
Column 19-30	Observed station label.
Column 33-41	Height difference.

3.1.3.13 Selected Error Ellipse Record

Column 1-3	Record type = 'ell' or 'el '
Column 5-16	From station label.
Column 19-30	To station label. If the first character in this label is '*', error ellipses between all stations and the same 'from' station will be selected.

3.1.3.14 Height Datum Record

Column 1-3	Record type = 'hgt' or 'ht '
Column 5-11	Height of datum to be used for the reduction of distances.

3.1.3.15 Standard Deviation Record

Column 1-3	Record type = 'sdv' or 'sd '
Column 6-9	Bearing standard deviation.

Column 11-14	Direction standard deviation.
Column 16-19	Distance standard deviation (constant)
Column 21-24	Distance standard deviation (ppm).

3.1.3.16 Bearing Set Record

Column 1-4	Record type = 'bset'
Column 6-8	Provisional orientation. Degrees
Column 9-10	Minutes
Column 11-14	Seconds
Column 16-35	Name associated with set if required.
Column 37-40	Centering standard deviation for set bearings in centimeters.

3.1.3.17 Distance Set Record

Column 1-4	Record type = 'dset'
Column 6-11	Provisional scale parameter value in ppm.

3.1.3.18 End of Data Record

This record can be used but is not essential. For the G77 versions of the program it is essential that the last data record be terminated with a carriage return. If not the record is ignored.

Column 1-2	Record type = 99
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3.1.4 Other Input Files

The program checks for the existence of several types of file which may contain data to be used for the adjustment process. If any of the files are not found it is assumed that the supply of this type of data is not required.

3.1.4.1 Command Line Argument File

The program will open a file called HAVOC.CMD if it is available and read the usual command line arguments from the first record. This file can be used for entry of input and output file names if the program is not being run from the command line.

3.1.4.2 Option File

The program reads a file called HAVOC.OPT that can be used to specify default options and disk drives and paths to be used for file storage. If the file does not exist, the program continues running with files opened in the program directory and the options that have been selected in the option record.

There are four types of file that can be assigned to a disk drive and path. These are the input, output, station data and work files.

As HAVOC.OPT is read, the file type is recognised by the first four characters of the line. Because of this, lines in the file can appear in any order. Any line not matching a file type or an option record is ignored.

The words recognized by the program are 'input', 'output', 'work' and 'data'.

The drive letters recognised by the program are the letters 'A' to 'Z' and 'a' to 'z' except for the characters 'x' and 'X' which are ignored. The path must be preceded by the character '=' and no blanks are allowed within the path string.

The program runs much faster if the work files are assigned to the RAMDRIVE. This is the usual way of utilising extended memory.

If an option record ('01') is found in this file, options selected in this record are added to the option record entered with the adjustment data. If required the entire option record can be held in the file HAVOC.OPT so that it is not necessary to include one with the input data.

Option selection characters are transferred from the file only if the corresponding character in the option record with the adjustment data is blank. Therefore options selected with the input data have precedence.

An example of an option file is shown in Appendix B.

3.1.4.3 Geoid File

A file can be used to enter geoid values if required. This is accessed using the station label and so can be used only with the label format. The file can be named 'geoid.dat' or can have a name formed by attaching the extension '.ged' to the input file.

The record structure is as follows.

Column 1-12	Station label
Column 14-20	Geoid-ellipsoid separation
Column 22-27	Vertical deflection in meridian
Column 29-34	Vertical deflection in prime vertical

3.1.4.4 Station Information Files

The program searches for coordinate and height values in seven different types of file if they have not been entered in the adjustment file. The search is done by opening each of these files in the order given below. Stations without coordinates are searched for in the currently open file

If any or all of the files do not exist or the station cannot be found, the program computes the coordinates using the available observations.

An option is also available for searching for coordinates of all stations regardless of whether their coordinates have been entered or not. This can be selected by entering 'C' in column 10 of the control record.

If more than one of these files are available for searching the following procedure is used to avoid the situation in which coordinates for a station are stored in more than one file and the coordinates in one of the files are preferable to another.

If the information for a station has been found in file 1 no other files are scanned for that station. If the information is found in file 2, the SCIMS file, and the station status has been set to fixed no other files are scanned for that station.

The number of the file used to obtain station information is shown under the heading 'Source' with other station data in the output file.

The files are opened in the following order using names that are determined by the program. They are opened in the working directory or using a path that has been specified in the option file explained in Section 3.1.4.1. For these files the keyword in the option file is 'data'.

3.1.4.4.1. HAVOC Stations File

This file with a name based on the input file name with the extension '.stn' has the format of HAVOC station data as described in Sections 3.1.2.5 and 3.1.3.1 and 3.1.3.2.

3.1.4.4.2. SCIMS Text File

This file named 'scims.dat' or with the extension '.scm' based on the input file name, has the format of a SCIMS or SCIMS 2000 radial or polygon search text file. If the adjustment zone has not been entered, the first zone value read from the file will be used for the adjustment.

3.1.4.4.3 SCIMS Comma Separated File

This file must be named 'scims.csv' or 'input file'.csv. It is a comma separated SCIMS file obtained from the ESRI system. The standard file heading is used to determine the field positions of the data in the file records. If field positions change the new heading must be included. This situation could occur in the case of concatenated files.

Station coordinate values are obtained from the easting and northing fields of this type of file. If the zone value in the file is different from the zone entered for adjustment, the coordinates are converted to the adjustment zone. If the adjustment zone has not been entered, the first zone value read from the file is used for the adjustment.

3.1.4.4.4 GDA94 Stations File

If the adjustment is on the GDA94 datum, a file named 'gda94.dat' is opened. The format is that of a modified NEWGAN result file.

3.1.4.4.5 GEOLAB Result File

This file, which must be named 'geolab.lst', is a GEOLAB output file. The record used to obtain coordinate data is identified as 'NEO'.

3.1.4.4.6 HAVOC Stations File

This file, which must be named 'stations.dat', has station data stored in the HAVOC stations format as described in Sections 3.1.2.5 and 3.1.3.1 and 3.1.3.2. If the file contains geographic coordinates and the adjustment zone has not been entered the zone is determined from the first station coordinates read. When this file contains geographic coordinate records, the class and order for stations can be entered in columns 105 and 106 for class and column 108 for order. The program determines the station status based on the order.

3.1.4.4.7 SCIMS Source File

This file with a name based on the input file name with the extension '.src' has the format of a SCIMS source data file. This file is produced by HAVOC as it extracts station data from a SCIMS text file for stations to be held fixed in the adjustment. The SCIMS source file is described in Section 3.2.18.5.

3.1.5 Values Entered With Decimal Points

Many of the values supplied to the program are interpreted as floating point values. If decimal places are required, the decimal point must be entered. The decimal point is not assumed to be in any particular position in the field. The number of decimal places allowed is limited only by the size of the field allocated for the value.

3.2 Output

The output of the program is stored in a disk file for viewing or printing. The name of the file is based on the name of the input data file with the extension '.prt' or is the name entered on the command line used to run the program.

3.2.1 Options

Page one of the output shows the options requested in the control record. Many of the options are shown in this section of the output only if they have been selected. They are shown in the following order.

- The zone number.
- Grid reduction request.
- Direction and azimuth (C-O) limit either as specified or the default value.
- Distance (C-O) limit as specified or the default value.
- The stage of processing required.
- The number of iterations selected if more than one.
- The analysis option selected for error ellipse output.
- The factor used for direction standard deviations.
- The centering standard deviation to be applied to azimuth, bearing and direction standard deviations.
- The variance factor limit for the limiting of adjustments to stage two.
- Selection of output of observation equations.
- Selection of output of normal equation solution.
- Selection of station summary output.
- Selection of the suppression of stage one observation output.
- Selection of the computation of azimuths and distances from provisional coordinates.
- The factor used for the reduction of observed distances.

3.2.2 Provisional Coordinate Calculation Output

The program will calculate the coordinates of any station for which coordinates have not been entered. The calculation is carried out using the observations supplied as input data. This output is intended mainly for verification purposes. It shows the observations used for the coordination of each station. An option for suppressing this output is available using column 30 of the option record.

The information shown consists of the method used for the coordination, the number of the station coordinated and the observations and stations used.

3.2.3 Station Information

This section shows the stations used in the adjustment. Information consisted of station number, name, coordinates and status. The order of the stations is the re-arranged order for minimizing the bandwidth.

If station coordinates have been retrieved from an external file the source of the coordinate values is shown with the station information. The source file number used is the one described in Section 3.1.4.4.

If a standard deviation for either an easting or northing has been entered for a station it will also be printed. For each standard deviation entered the program will include a position equation using a weight computed from the value entered. The program treats the provisional coordinate entered for the station as the observed value for the coordinate. Each position equation is an observation in the adjustment.

3.2.4 Bearing and Azimuth Observations

For Laplace observations the astronomic values for longitude, latitude and azimuth, the elevation angle, the geodetic values for longitude and latitude and the computed Laplace correction and deflection correction are printed on the same line as the station numbers.

The second line shows the reduced azimuth, the convergence, the arc-to-chord correction, the reduced bearing, the computed bearing, the difference between the reduced and computed bearings, the standard deviation and the weight computed from the standard deviation.

If the value is entered as an azimuth, only the second line as described above will be printed with the 'FROM' and 'TO' station numbers. If the value is entered as a plane bearing the convergence and arc-to-chord corrections are omitted.

Azimuth and bearing values derived from cartesian coordinate difference observations are indicated by attaching the character 'C' to the value.

3.2.5 Direction Observations

Data printed are the observation number, the station numbers, observed direction, arc-to-chord correction if required, followed by the reduced bearing (computed from bearing to R.O. plus angle between R.O. and current station), computed plane bearing from coordinates, their difference, standard deviation and weight computed from the standard deviation.

If reduction to centre is required the corrected direction is printed adjacent to the observed direction and the occupied and observed eccentric mark numbers are also printed.

3.2.6 Distance Observations

The information printed is similar to that for directions. The reduced plane distance is the observed distance multiplied by the line scale factor. If a distance reduction factor is entered in the control record, the scaled distance is printed after the observed distance.

If reduction to centre is required, the corrected distance is printed adjacent to the observed or reduced distance and the occupied and observed eccentric numbers are shown.

A distance will be regarded as a sea level distance unless it is indicated as being one of the following types. A distance entered as a slope or spatial distance is printed with the character 'S' appended. A distance entered as a horizontal distance is printed with the character 'H' appended. A distance entered as an ellipsoidal distance is printed with the character 'E' appended and a distance entered as a plane distance the character 'P'.

If a distance entered as a slope distance is reduced to centre, the reduced to centre value is converted to a slope distance and indicated with the character 'S'. The eccentric mark height differences are used in the height reduction.

A distance entered with type 'X' is converted from a sea level distance to a slope distance. The purpose of this option is not for adjustment but to provide a utility for this type of conversion.

Distance values derived from cartesian coordinate difference observations are indicated by attaching the character 'C' to the reduced distance value.

3.2.7 Adjustment Size Information

After the observation equations have been computed, statistics indicating the size of the job are printed. The information printed is the numbers of stations, fixed stations, azimuths, directions, distances, position observations, followed by the number of observation equations formed, the order of the normal equation matrix, width of diagonal band and number of coefficients stored.

3.2.8 Solution of Normal Equations

The solution for each parameter is printed together with its column number and the station number of the associated station. For each adjusted station the first two associated variables

are corrections to the easting and northing and subsequent variables are orientation corrections for sets of directions or bearings from that station. Units of corrections are decimetres.

3.2.9 Residuals

The term 'residual' is defined as the difference between the value computed from the adjusted coordinates and the observed value. It is equivalent to and has the same sign as the (C-O) term which is the computed minus observed value for each observation before the adjustment. The term 'correction' is sometimes used for this quantity.

The residuals for all observations after adjustment are listed with the sequence number of the observation and its station numbers and names. Adjacent to this the standard residual is printed. This is obtained by dividing the residual by the standard deviation. The length of the observed line is also printed.

In addition to this, information relating the residual to the length of the line is also given. In the case of directions an offset from the adjusted direction to the observed station is printed. For distances the residual is also shown as a parts per million value.

As the units of distance used in the adjustment are decimetres, the computed distance residuals are also in decimetres. These are converted to metres for output.

3.2.9.1 Summations

Two summations are printed after the list of residuals. These are the sum of the weighted squares of residuals, PVV (the quantity to be minimized) and the sum of the weighted products of the residuals and the original right hand sides of the observation equations, PLV. If the adjustment is sound, these two quantities should be opposite in sign and nearly equal in magnitude.

The estimate of the variance factor is obtained by dividing the value, PVV, by the number of redundant observations. The estimate obtained should be close to 1.0 if the standard deviations of the observations have been estimated correctly.

If the variance factor is less than 1.0 it indicates that the residuals are small in comparison with the estimated standard deviations of the observations. In this case the standard deviations should be reduced and the adjustment run again. If the variance factor is greater than 1.0 it indicates that the observation standard deviations have been under estimated or that there are large residuals on one or more observations.

3.2.9.2 Analysis

The summation of the residuals within intervals and the maximum, minimum, mean and standard deviation of residuals are printed. One unit intervals up to four units are used for standard residuals. One second intervals up to four seconds are used for azimuth and direction residuals. For distance residuals interval summation is done for the residuals and for the parts per million values.

The distance residual intervals are in units of millimetres, centimetres or decimetres depending on the standard deviation of the residuals. The interval to be used is determined by the program. For parts per million residuals, two parts per million intervals up to eight parts per million are used.

The observation numbers for the observations having the maximum and minimum residuals are also shown so they can be easily located in the residual output.

Interval summations are printed in four sections. The first provides an analysis of standard residuals for all observations, the second for residuals of azimuth and bearing observations, the third for direction observations and the fourth for distance observations.

3.2.10 Adjusted Coordinates

This section of output shows the coordinates of each station after adjustment. The information printed for each station consists of the number and name, the provisional coordinates, the computed corrections and the adjusted coordinates.

3.2.11 Adjusted Bearing Set Orientations

If sets of bearings have been entered, the information printed for each set consists of the provisional orientation, the orientation correction and the adjusted orientation.

3.2.12 Adjusted Scale Factors

If auxiliary scale parameters for distance observations have been included the information printed for each set is the provisional scale factor, the correction and the adjusted scale factor.

3.2.13 Matrix Output

If required, the normal matrix and the inverse matrix can be printed. This process was included for testing purposes and should rarely be needed. The matrices are printed in upper triangular form.

3.2.14 Error Ellipse Information

Error ellipse parameters for the lines selected and all lines observed are listed after the final coordinates. The information printed is given below.

- The numbers and names of the two stations selected. If one of the stations is fixed an asterisk is printed after the number.

- The precision of the difference between the easting values of the two stations and northing values of the two stations expressed as standard deviations in metres and the covariance.
- The ellipse parameters are printed in the form of the semi-major axis and semi-minor axis in metres, the orientation of the major axis in degrees and the ratio major axis/minor axis. The values are converted to a 95% confidence region before printing using a multiplication factor of 2.45.
- The line precision is given as the standard deviation of the distance in metres and in parts per million and the standard deviation of the bearing in seconds. These are also 95% confidence region values.
- The variance factor used for the computation of error ellipses is printed in the heading. This is 1.0 unless the option requesting the use of the adjustment variance factor is selected using column 66 of the control record.

If requested station point ellipses are printed after the relative ellipses. This option can be selected by entering '2' in Column 64 of the '01' record or entering the character 'e' in the '02' record.

3.2.15 Geographical Coordinates

The stations are printed in alphabetical order together with latitude, longitude, zone, easting, northing, grid convergence and point scale factor. If a station is in a zone overlap, coordinates in the overlap zone are listed. If the coordinates are AMG, then the corresponding ISG coordinates are listed, and vice versa.

3.2.16 Station Summaries

If requested, station summaries for each station in the adjustment are printed in the same order as the list of geographical coordinates.

The station summary consists of the station name, geographic and grid coordinates, zone number and convergence. This is followed by information showing the adjusted azimuth, adjusted spheroidal distance, arc-to-chord correction and line scale factor for each station connected by observation in the adjustment or specifically requested as described in Section 2.12.

An expanded station summary can be selected using column 48 of the option record, to show additional information consisting of the plane bearing and the plane distance. If a scale factor has been used to reduce the observed distances, the distance with the scale reduction removed is also shown. This is called the unscaled distance.

For adjustments in which a scale factor based on the average network height has been used to reduce distances from ground to sea level, the unscaled distance is equivalent to the adjusted ground distance. In this case the distance heading is changed to adjusted ground distance.

If station heights have been entered, the slope distance is also shown when the expanded station summary option is selected. An option is available for the output of a distance reduced to the mean height of the connected stations. This can be selected by entering '3' in column 48 of the option record.

3.2.17 Station Data Output Files

If the option four is selected for the stage of processing option in the control record, a file of adjusted coordinates will be output. This is a text file which was used to update the now superseded Geodetic Control Register and SCIMS databases and for the plotting of geodetic control networks. There is one record for each station. Although this file is no longer used for data base update it can be used for other applications requiring the input of station information.

As the file format for the update of the Geodetic Control Register was slightly different from the SCIMS update file format, it is necessary to select the latter format in the option record.

3.2.17.1 Geodetic Register File Format

The name of the file is created by the program. It is based on the name of the input file with the extension '.crd' added.

Column 1-2	Record type = 10
Column 3-22	Station name
Column 24-28	Geodetic control register number
Column 30-32	Adjustment number
Column 33-44	Easting
Column 45-56	Northing
Column 57-59	Zone number
Column 60-67	Height
Column 73-76	Number of adjustment (free stations only). If a value has not been entered in the '01' record a dummy value of -999 will be used. The PC version indicates a fixed station using an asterisk in column 80 and the adjustment number is regarded as zero.
Column 78	Category of adjustment (free stations only)

The last station record is followed by a '98' record with 98 entered in columns 1 and 2. This is followed by a '99' record to signify the end of the file. There is no printed output from this section of the program.

3.2.17.2 SCIMS File Format

The name of the file is created by the program. It is based on the input file name and has the extension '.dat' substituted or added and the character 'i' attached to the beginning of the name.

Column 1-2	Record type = 10
Column 3-22	Station Name
Column 33-42	Easting
Column 45-55	Northing
Column 57-59	Zone number
Column 80	The character, '*', to indicate a station held fixed in the adjustment.

The last record is followed by '98' and '99' records as described above.

3.2.17.3 Station Data File

If output of station data is selected using column 56 of the option record, station data output with the same format as the station input record is produced. The name given to the file by the program is based on the input file name with the extension '.stn' added. This file can be used to provide station data to the program TRGLEV and other programs. It can be produced in addition to the stage four file described above.

If '1' is entered in column 56, grid coordinate records are produced. If '2' is entered, geographical coordinate records are produced. The file is produced in stage one of the adjustment and updated when the adjustment is completed.

This file is overwritten each time the program is run with the same input file. The program also reads this file to obtain station data. To create a permanent read only file with the same format the name 'stations.dat' can be used. The program never writes data into this file.

3.2.18 Other Output Files

Additional information resulting from an adjustment can be obtained from a number of optional output files described below. These files have names based on the name of the input file with an extension added by the program. Most of them are produced in stage one of the adjustment so they can be used for analysis of the adjustment data before running the full adjustment.

3.2.18.1 Number Format Input File

This file is the equivalent number format of the HAVOC data set. It is needed for the plotting programs and some other utilities. The extension given to the file is '.num'. It is produced when column 50 of the option record is set to '6'.

3.2.18.2 Azimuth File

A file of azimuth observations derived from cartesian coordinate differences can be produced. This file has the extension '.azm'. It can be obtained by entering '4' in column 50 of the '01' record or the character 'a' in the '02' record.

This option can also be used for producing an input file of azimuth values converted from ISG bearings. This is needed occasionally for converting ISG data sets to MGA.

3.2.18.3 Azimuth and Distance File

A file of azimuth and distance observations derived from bearing and distance observations can be produced. The file has the extension '.ads'. It can be obtained by entering '4' in column 50 of the '01' record or the character 'a' in the '02' record.

3.2.18.4 Survey Plot Data

A file of stations and connections can be produced for plotting a network using a TCL program. This file has the extension '.spd' and will be automatically produced whenever the program is run.

3.2.18.5 SCIMS Report File

This file is produced when a SCIMS data file is accessed. It contains a list of stations found in the SCIMS file and which have coordinates held fixed in the adjustment. Information given in the file includes the class, order, source adjustment and height information for each mark. The file has the extension '.src'.

3.2.18.6 Connection Information File

A file showing all stations with connection information for each will automatically be produced for analysis of the network. Stations that are radiated, intersected, resected or unoccupied are indicated. Also stations that are used for orientation or are not well connected are indicated. For each station a maximum of ten connected stations is shown.

If the unconnected station option is selected the program searches for unconnected stations within a specified distance. The output from this search is shown at the end of the file. The file is output for the first iteration only. It has the extension '.con'.

3.2.18.7 Geolab Data

Station and direction and distance data can be output in Geolab format by entering '2' in column 34 of the '01' record or the character 'g' in the '02' record. The station file has the extension '.apx' and the observation file has the extension '.cob'.

3.2.18.8 Civilcad Data

Station data can be obtained in Civilcad format by entering '2' in column 50 of the option record. The file has the extension '.civ'.

3.3.18.9 Minicad Data

Station data can be obtained in Minicad format by entering '3' in column 50 of the option record. The file has the extension '.min'.

3.2.18.10 Class File

To analyse the uncertainty of the coordinates resulting from an adjustment, a file showing class based on relative error ellipses can be obtained. This file is obtained by entering '3' in column 66 of the '01' record or the character 'c' in the '02' record. If '4' is entered in the '01' record the ellipse axes are scaled by the variance factor.

The file shows connected and, if requested, unconnected stations with the semi-major axis of the relative ellipse, the distance between the stations and the class determined from these values. The file has the extension '.cls'.

3.2.18.11 Distance Report File

A file showing each step used for the reduction of distances can be obtained. The distance reductions are described in Section 2.2.5. The report file shows all the information used for the reduction of each distance.

When ISG distance values are entered, the computed ANS ellipsoidal values are shown as well as the GRS80 ellipsoidal values. The latter values are obtained by determining a scale difference from the difference in the geoid-ellipsoid separations.

This file can be obtained by entering the character '2' in column 32 of the '01' record or the character 'd' in the '02' record. The file has the extension '.dis'.

3.2.18.12 Cartesian Coordinate Computation Report File

A file showing the values used for the processing of cartesian coordinate differences can be obtained if required. This can be used to check the results of the computation. The option is

selected by entering the character 4 in column 38 of the option record. The output file has the extension '.xyz'.

3.2.18.13 Adjustment Report File

A file showing a summary of input data and observation data and options used can be obtained to assist in the analysis of the adjustment result. The file has the extension '.rpt'. This file is produced automatically. It can only be obtained for data in the station label format. It can be suppressed by entering a '0' in column 80 of the option record.

Information included in the file are the statistics used for the adjustment analysis and some information on the standard residuals. The file will also contain radiated and unoccupied station information obtained from the connection file, and flagged residuals obtained from the output file. Also shown are observations with zero residuals because they indicate lack of redundancy in the network.

The report also contains information on distances between all stations in the network. The program computes all distances and reports on all distances less than 0.5 metres. This can be useful in detecting the use of different labels for the same station. It also reports the maximum and minimum distances computed for the network

3.2.18.14 Extract of Output File

An option is available for the output of an 80 column extract of the output file using column 80 of the option record. If this is selected an 80 column file is produced which contains most of the information in the output file. The file has the extension '.ext'. This option is not available in the DOS version of the program because of memory limitations. A separate program called HAVOCEXT can be used to produce the extract if required.

3.2.18.15 Copy of Input File

When the program modifies data in the input file it produces a copy of the input file in case program or system failures prevent the completion of the adjustment process. This file is produced when the option for entry of DP data is selected using column 11 of the option record and the input file has the extension '.hav'. In this case the program modifies the input file by removing duplicate observations and creating a new input file with the extension '.hav'.

When a '3' is entered in column 56 of the option record to request the inclusion of adjusted station coordinates in the input file, a copy of the input file is produced. The copied file has the extension '.cpy'.

4. PROGRAM ERROR MESSAGES

The program outputs a number of error messages related to the amount of data to be processed and also to provide information on data integrity. It has been designed to detect and report as many errors as possible in one run. This allows the user to edit the dataset to remove all inconsistent data in one editing session.

4.1 Program Capacity

Because of the arrays used for data storage within the program there are limits to the amount of data the program can process. These array sizes could be changed if required. The current limits for different versions of the program are given below.

	HAVOC	HAVOCL	HAVOCXL
Number of stations:	1000	2000	4000
Number of observations:	8000	12000	20000
Number of normal equations:	4000	8000	15000
Number of directions per set:	80	80	80
Number of sets for a station:	20	20	20

The following error messages are printed if the program capacity is exceeded in any of the above areas. Processing is then terminated.

4.1.1

*** TOO MANY STATIONS ***

More than the maximum allowable number of stations have been entered.

4.1.2

*** NO OBSERVATIONS HAVE BEEN HAVE SUPPLIED ***

No observation records have been included in the input file.

4.1.3

*** TOO MANY OBSERVATIONS ***

More than the maximum allowable number of observations have been entered.

4.1.4

*** TOO MANY NORMAL EQUATIONS ***

More than the maximum number of unknowns have been generated.

4.2 File Opening Errors

When the program is run it initially opens eleven work files. It then opens the input and output files. After reading the option record it opens other files required for optional output. With the selection of options there could be up to twenty files opened.

The opening of this number of files could cause system errors if the system configuration has not allowed sufficient space for file buffers.

4.3 File Initialisation

When the program starts it sets up files to be used for data storage. Error messages associated with the initialisation of program files are as follows.

4.3.1

*** ERROR OPENING CO-ORDINATE FILE ***

For stage four adjustments a file for the storage of adjusted coordinates is opened in this section of the program for use later. The above message indicates that this file cannot be opened.

4.4 Option Record

The various options available in the program for processing the data are selected using the option record which has a record type '01'. This also can be used to supply some of the data that could be needed by the program.

There are several error messages associated with the interpretation of this record. They are as follows.

4.4.1

*** ERROR IN ZONE NUMBER ***

The zone number field contains illegal characters or is outside the allowable range.

4.4.2

*** STAGE OF PROCESSING MUST BE 1, 2, 3, OR 4 ***

Minimum stage of processing is 1 and maximum is 4.

4.4.3

*** ZONE NUMBER NOT SPECIFIED FOR GEODETIC CORRECTION ***

If geodetic correction is required the zone number must be entered.

4.4.4

*** INCORRECT DATUM FOR GDA TRANSFORMATION OPTION ***

The transformation option can be selected only when the datum selected in the option record is AGD. This would be chosen by entering an AMG or an ISG zone value.

4.5 Station and Observation Data

As data is read from the input file various checks on the validity of each data item are carried out. Error messages related to these are described below. The record in which the error occurred is also shown in the station number format described in Section 3.1.2.

Records, in which errors of this type are found, are ignored by the program and processing continues. A message to indicate this is also shown.

Errors in station coordinates can occur if a file of station coordinates has been created for another network and is used by the program to obtain coordinates. If station coordinates are not entered with station information, the program will look for coordinate values in existing files before computing them.

Seven file types are read by the program to obtain station information.

1. '.stn' file, a temporary HAVOC station file.
2. scims.dat or '.scm' file, a SCIMS radial search file.
3. SCIMS '.csv' file.
4. gda94.dat, a file of GDA94 stations.
5. geolab.lst, a GEOLAB output file.
6. stations.dat, a permanent HAVOC station file.
7. SCIMS '.src' file.

4.5.1

*** ERROR IN RECORD TYPE OR RECORD OUT OF ORDER ***

A record type not recognised by the program has been entered or a record of a certain type is not in the correct position in the input data.

4.5.2

***** ERROR IN STATION NUMBER *****

The number entered for a station is either zero or contains illegal characters.

4.5.3

***** ERROR IN EASTING *****

The easting value entered for a station contains illegal characters.

4.5.4

***** ERROR IN NORTHING *****

The northing value entered for a station contains illegal characters.

4.5.5

***** ERROR IN STATUS *****

The status entered for a station must be blank, a minus sign or an asterisk.

4.5.6

***** ERROR IN OCCUPIED STATION NUMBER *****

The occupied station number entered in an observation is either zero or contains illegal characters.

4.5.7

***** ERROR IN OBSERVED STATION NUMBER *****

The observed station number entered in an observation is either zero or contains illegal characters.

4.5.8

***** ERROR IN OBSERVED DIRECTION *****

The observed direction entered contains illegal characters. An entirely blank field is interpreted as a request for an azimuth and direction to be included in the station summary output.

4.5.9

*** ERROR IN OBSERVED DISTANCE ***

The observed distance entered contains illegal characters. A blank distance is interpreted in the same way as a blank direction.

4.5.10

*** ERROR IN STANDARD DEVIATION ***

The standard deviation field for an observation contains illegal characters.

4.5.11

*** ERROR IN AZIMUTH OR BEARING ***'

An azimuth or bearing field contains illegal characters.

4.5.12

*** ERROR IN BEARING SET PROVISIONAL ORIENTATION ***

The provisional orientation field for a set of bearings contains illegal characters.

4.5.13

*** ERROR IN X/Y/Z CARTESIAN COORDINATE DIFFERENCE ***'

The cartesian coordinate difference field for the X, Y or Z components contains illegal characters.

4.5.14

*** ERROR IN HEIGHT DIFFERENCE BETWEEN STATIONS 'M' & 'N' ***

This message occurs only for supplementary adjustments when height difference information is entered. It indicates that the height difference between stations numbered 'M' and 'N' entered in a height difference record, differs by more than 10 mm. from the height difference derived from the values entered as eccentric height differences.

4.6 Provisional Coordinate Computation

The program attempts to compute provisional coordinates for stations entered without them. Only one error message is printed in this stage of the program.

4.6.1

*** STATION 'N' NOT FOUND ***

This message is printed if a station number appearing in an observation cannot be found in the list of stations.

4.7 Station Processing

Station information is printed in the order resulting from re-arrangement for the minimisation of the bandwidth. The following messages can appear with the station information.

4.7.1

*** Omitted ***

This is an advisory message to indicate that a station included in the data is not connected to another station or cannot be coordinated using the available observations. The station is omitted and processing continues.

4.7.2

Insufficient data to compute coordinates

For the station indicated the program was not able to compute provisional coordinates or find them in a file. The station is omitted and processing continues.

4.7.3

Station not found in an observation

The program has checked all observations and has not found the station. The station is omitted to prevent a zero term occurring on the diagonal of the normal matrix. Processing continues.

4.7.4

Station number has already been used

The number allocated to a station has already been allocated to another station. As this will cause a zero term on the diagonal of the normal matrix, the station is omitted and processing continues.

4.7.5

Repeated label with different station data

A station label has been used before with either a different status or, if both occurrences are indicated fixed, the coordinates are different.

4.7.6

*** TRANSFORMED ***

A warning message that the station indicated as fixed in the adjustment has coordinates that have been transformed to GDA94.

4.7.7

*** ORIENTATION ***

The status of an orientation station has been changed to fixed so that the normal matrix will not become singular during the solution.

4.8 Observation Processing

As the observation equations are formed, checks on the consistency of the observation data are made. Error messages printed at this stage are described below. If errors are detected, processing of all observations continues but the program stops after stage one is completed.

4.8.1

*** OCCUPIED STATION NUMBER NOT FOUND IN STATION LIST ***

The occupied station number in the observation being processed cannot be located in the list of stations.

4.8.2

*** OBSERVED STATION NUMBER NOT FOUND IN STATION LIST ***

The observed station number in the observation being processed cannot be located in the list of stations.

4.8.3

*** (C-O) VALUE TOO LARGE ***

The difference between the computed and observed values for the observation being processed exceeds the specified value.

4.8.4

*** STATIONS HAVE THE SAME CO-ORDINATES ***

The occupied and observed stations in the observation being processed have the same coordinate values.

4.8.5

*** INSUFFICIENT DIRECTIONS IN THE ABOVE SET ***

A set of directions from a station contains only one direction or all but one have been rejected.

4.8.6

*** THIS SET NUMBER FOR THIS STATION HAS APPEARED BEFORE OR IS OUT OF ORDER ***

A set number for a particular station has been used more than once.

4.8.7

*** THIS SET NUMBER FOR THIS STATION IS OUT OF ORDER OR A SET NUMBER HAS BEEN MISSED ***

The set numbers for the station concerned are not arranged in numerical order.

4.8.8

*** TOO MANY DIRECTIONS IN THE ABOVE SET ***

More than 80 directions have been entered in one set. The set will have to be replaced by two sets.

4.8.9

*** HEIGHT NOT AVAILABLE FOR CALCULATION OF CARTESIAN COORDINATES. ZERO USED. ***'

To compute cartesian coordinates for a station the ellipsoidal height is required. The station height was not entered so it was assumed to be zero.

4.9 Normal Matrix Formation and Solution

4.9.1

The normal matrix is stored, solved and inverted in memory if it fits into the storage arrays available in the program. If the matrix is too large to be stored in memory, the program creates work files for matrix processing. If the work files cannot be created the following message is printed.

*** UNABLE TO OPEN WORK FILES FOR MATRIX PROCESSING ***

4.9.2

The presence of zero terms on the diagonal of the normal matrix during formation or solution indicates an unstable network. In this situation a solution cannot be obtained for the adjustment. The following error messages indicate such instability.

*** ZERO ON DIAGONAL IN COLUMN 'N' ***

During the formation of the normal equations a zero has occurred on the diagonal of the matrix in column numbered 'N'. This usually is the result of a station in the adjustment having no connections. The program checks for this at an earlier stage and deletes any station that could cause this situation.

The error message can also occur when the option for removal of distances between fixed stations is selected and there are scale parameters dependent on these distances for solution.

4.9.3

*** MATRIX SINGULAR. DIAGONAL BECAME ZERO IN COLUMN 'N' ***

*** STATION INVOLVED IS 'M' ***

During the solution of the matrix a diagonal term has become zero. The column number is shown as 'N' and the station number is shown as 'M'.

This usually occurs when a station is not fixed by sufficient observations. It indicates instability in the network in the vicinity of the station shown.

4.10 Station Summaries

In the station summary section of the output the following advisory messages are printed when appropriate.

4.10.1

*** PROVISIONAL CO-ORDINATES USED ***

The station coordinates shown and the information derived from them are approximate and not adjusted values.

4.10.2

*** ERRORS HAVE OCCURRED IN ECCENTRIC HEIGHT DIFFERENCE DATA

This applies to supplementary adjustments only. It indicates that height difference information has been entered and is not compatible with the eccentric height differences entered.

4.10.3

*** AN ADJUSTED LENGTH OF MORE THAN 50 KMS HAS OCCURRED ***

In a supplementary adjustment a length of more than 50 kilometres from the main station to an observed station has occurred.

Appendix A

Theory and Formulae

1. Reduction of Observations to Grid

Observations are adjusted either on a plane or on one of the following four map grids:

1. The Australian Map Grid (AMG) based on the Australian National Spheroid and the Universal Transverse Mercator (UTM) projection system,
2. The New South Wales Integrated Surveys Grid (ISG), based on AMG and UTM,
3. UTM projection based on the WGS72 geodetic datum,
4. The Map Grid of Australia (MGA) based on the Geodetic Datum of Australia (GDA94).

Since observations are assumed to be reduced to the ellipsoid on input, they must be reduced to the appropriate grid before adjustment, by applying arc to chord corrections to directions and line scale factor to distances. For formulae used, see the Geocentric Datum of Australia Technical Manual.

2. Observation Equations

The program will process four types of observation. These are azimuth, direction, distance and position observations. For each observation entered an observation equation is formed and used in the adjustment.

Let E_i, N_i be the provisional coordinates of the occupied station (i)

Let E_j, N_j be the provisional coordinates of the observed station (j)

Let E^o_i be the observed value for the easting of station (i)

Let N^o_i be the observed value for the northing of station (i)

Let θ^o be the observed plane bearing i to j

Let θ^c be the computed plane bearing i to j

Let L^o be the observed plane distance i to j

Let L^c be the computed plane distance i to j

Let $\Delta E_i, \Delta N_i$ be the corrections to the provisional coordinates of station i computed in the adjustment.

Let ΔE_j , ΔN_j be the corrections to the provisional coordinates of station j computed in the adjustment.

The plane distance L^c is given by

$$L^c = ((E_j - E_i)^2 + (N_j - N_i)^2)^{1/2}$$

and the plane bearing is given by

$$\theta^c = \tan^{-1} \frac{E_j - E_i}{N_j - N_i}$$

The observation equations used are as follows.

For an Azimuth or Bearing

$$-a_{ij}\Delta E_i + b_{ij}\Delta N_i + a_{ij}\Delta E_j - b_{ij}\Delta N_j = \theta^o - \theta^c \dots\dots\dots(1)$$

For a Direction

$$-a_{ij}\Delta E_i + b_{ij}\Delta N_i + a_{ij}\Delta E_j - b_{ij}\Delta N_j - \Delta z = \theta^o - \theta^c \dots\dots\dots(2)$$

where $a_{ij} = \frac{N_j - N_i}{S^2 \sin 1''}$, $b_{ij} = \frac{E_j - E_i}{S^2 \sin 1''}$ and Δz is the set orientation correction

and where $S = L^c$

For a Distance

$$(\Delta N_j - \Delta N_i) \cos \theta^c + (\Delta E_j - \Delta E_i) \sin \theta^c = L^o - L^c \dots\dots\dots(3)$$

For a Position

$$\Delta E_i = E^o_i - E_i \dots\dots\dots(4)$$

$$\Delta N_i = N^o_i - N_i \dots\dots\dots(5)$$

The program treats the absolute term of these equations as zero. In this case the observed value for the coordinate is used for the provisional value.

3. Weights

The weight to be applied to an observation equation is computed as follows:

$$W = 1/\sigma^2 \quad \text{for directions(6)}$$

$$W = 1/(C + pL/10^6)^2 \quad \text{for distances(7)}$$

where σ is the standard deviation for a single direction in seconds of arc, C is the constant part of a standard deviation for distances in centimetres, and p is the parts-per-million term of a standard deviation for distances.

4. Units

The reduction of observations is carried out using units of metres. The adjustment, however, is carried out using decimetres. Therefore, in equations (1) and (2), all the coefficients will be divided by 10, and in equation (3) the term ($S^\circ - S$) will be multiplied by 10. Equation (5) becomes:

$$W = 1/(C/10 + pL/10^5)^2 \text{(8)}$$

5. Assignment of Unknowns to Stations

In the formation of the observation equation coefficient matrix, the number of coefficients to be generated for each observation equation is equal to the total number of unknowns to be solved. This number is computed on the basis of two coordinate corrections for each unfixed station, one orientation correction for each set of observed directions and bearings and one scale unknown for each set of observed distances. In practice, the maximum number of non-zero coefficients is 5 for each observation equation. Unknowns are allocated for an individual observation equation as follows:-

- (i) one, for an observed direction or distance with a scale correction between two fixed points.
- (ii) two, for a measured distance or a bearing between a fixed point and an unfixed point,
- (iii) three, for an observed direction or distance with a scale correction between a fixed point, and an unfixed point,
- (iv) four for a measured distance or bearing between two unfixed points,
- (v) five, for an observed direction between two unfixed points or for an observed distance with scale correction between two unfixed points.

Thus five coefficients are stored for each equation together with the serial number of the unknown to which that coefficient refers. These sequential numbers are called 'column numbers of coefficients'. If an equation contains less than 5 non-zero coefficients, the remaining coefficients and their column numbers are given the value zero.

6. Fixed Stations

Stations are held fixed by setting the coordinate corrections ΔE and ΔN to zero in the observations in which they occur. Therefore, in the program unknowns are not allocated to fixed stations.

7. Station Serial Numbers and Bandwidth

Each station is given a serial number on entry to the program. The station with the lowest serial number is allocated the first coefficients in the normal equations, and coefficients are allocated sequentially thereafter.

In most survey adjustments, observations generally occur between stations which are relatively close to one another. Occasionally lines extend from one end of a network to the other, though this is unusual.

Therefore, if the stations that are close together in the network can be allocated serial numbers which are also close to one another, the columns in the normal equation matrix which contain the coefficients for these stations will also be close to one another. In this case the non-zero coefficients in the matrix will tend to lie in a band parallel to the main diagonal. The width of this band, outwards from and excluding the main diagonal, is called the 'bandwidth'. Coefficients outside this band are zero and are not stored by the program.

The bandwidth may in most cases be minimised by the program. Two methods of doing this are used.

Firstly, the observation causing the maximum bandwidth is found. The FROM station for this observation is then allocated a serial number which has been computed as the mean of the maximum and minimum serial numbers to which it was connected. This procedure is iterated until no improvement in bandwidth can be made. This method assumes that the bandwidth is being caused by differences between the FROM and TO station serial numbers.

If the above method can make no improvement at all, it is assumed that the bandwidth has been maximised by a large difference between the maximum and minimum serial numbers of TO stations, in which case the serial numbers of these stations are meaned, and the mean number is given to the TO station in the observation causing maximum bandwidth.

When neither of these methods can make an improvement, it is assumed that the minimum bandwidth has been obtained.

8. Formation of Normal Equations

The observation equations form a set of m independent linear equations with n unknowns, where $m > n$. In order to obtain a unique solution, the equations must be normalised. The resulting solution then gives the most likely values for the unknowns.

Let A be the $m \times n$ matrix of coefficients,

Let X be the n x 1 matrix of unknowns,

Let K be the m x 1 matrix of absolute terms,

Let P be the m x m matrix of observation weights.

The observation equations are given by:

$$AX = K \dots\dots\dots(9)$$

The normal equations are given by:

$$N = A^T P A \dots\dots\dots(10)$$

and the solution of the unknowns is given by:

$$X = (A^T P A)^{-1} A^T P K \dots\dots\dots(11)$$

9. Solution of Normal Equations

The Cholesky or Square Root method is used to solve the normal equations. This method can be used on any symmetric matrix, such as a system of normal equations, and is particularly suited to a band matrix.

Equation (9) may be written as:

$$BX = C \dots\dots\dots(12)$$

where $B = A^T P A$

and $C = A^T P K$

The symmetric matrix B can be factorised into an upper triangular matrix S and its transpose S^T , such that

$$SX = Y \dots\dots\dots(13)$$

and $S^T Y = C \dots\dots\dots(14)$

Let S^T_{ij} be an element of S^T

Let Y_i be an element of Y

Let C_i be an element of C

Let S_{ij} be an element of S

Note that $S_{ii}^T = S_{ii}$

Then the elements of S and S^T can be found immediately:

$$S^T S = B$$

$$b_{ii} = S_{1i}^2 + S_{2i}^2 + S_{3i}^2 + \dots S_{ii}^2 \quad \text{for } i = j$$

and $b_{ij} = S_{1i}S_{1j} + S_{2i}S_{2j} + S_{3i}S_{3j} + \dots S_{ii}S_{ij} \quad \text{for } i > j$

From the above two equations, general rules for computing all S_{ij} can be found.

$$S_{11} = (b_{11})^{1/2}, \quad S_{1j} = b_{1j}/S_{11}$$

and $S_{ii} = (b_{ii} - \sum_{k=1}^{i-1} S_{ki}^2)^{1/2} \quad \text{for } i > 1, i = j$

$$S_{ij} = (b_{ij} - \sum_{k=1}^{i-1} S_{ki}S_{kj})/S_{ii} \quad \text{for } i < j, j > 1$$

$$S_{ij} = 0 \quad \text{for } i > j$$

The elements of Y can also be found immediately:

$$Y_1 = C_1/S_{11} \quad \text{for } i = 1$$

$$Y_i = (C_i - \sum_{k=1}^{i-1} S_{ki}Y_k)/S_{ii} \quad \text{for } i > 1$$

The elements of X can then be found by back-substitution.

10. Inversion of Normal Matrix

When the error ellipse option is selected for analysis of the adjustment or for optimization, the normal matrix has to be inverted to obtain the Q_x matrix. This can be used to provide variances and co-variances of the parameters obtained in the solution of the least squares adjustment.

The Q_x matrix is computed as:

$$Q_x = (A^T P A)^{-1}$$

The inversion of the matrix is computed during the Cholesky solution by repeating all the row operations on a unit matrix. This requires extra time for processing so is done only when the output of error ellipses is required.

11. Computation of Residuals

The residuals are computed as:

$$V = AX - K$$

where V is the vector of residuals and A, X and K are as above.

During the computation of residuals, two summations are carried out by the program:

$V^T P V$, the sum of the weighted squares of residuals, $P V V$, and
 $V^T P K$, the sum of the products of weight, residual and absolute term of each equation, $P L V$.

If the adjustment was sound (that is the observations were free of gross and systematic error, **with** weights corresponding to the accuracy of the observations) then these two summations should be equal in magnitude and opposite in sign.

If they are not significantly the same size, the fault may lie in the provisional coordinates, in which case the adjustment should be iterated with the updated coordinates as provisional coordinates.

12. Computation of Geographic Coordinates

Computation of latitudes, longitudes, point scale factors and convergence are carried out using Redfearn's formulae in full.

13. Computation of Azimuths and Ellipsoidal Distances

Azimuths and distances are computed from the adjusted grid coordinates

Let E_1, N_1 be the easting and northing of the FROM station

Let E_2, N_2 be the easting and northing of the TO station

Let δ be the arc to chord correction along the line 1 to 2.

Let γ be the grid convergence along the line 1 to 2

Let K be the line scale factor 1 to 2

Let s be the ellipsoidal distance

Let L be the plane distance

Let α_{12} be the azimuth 1 to 2

Let θ_{12} be the plane bearing 1 to 2

δ , γ and K are computed using Redfearn's equations.

Plane bearing is given by:

$$\theta_{12} = \tan^{-1} \frac{E_2 - E_1}{N_2 - N_1}$$

and the azimuth by:

$$\alpha_{12} = \theta_{12} - \delta - \gamma$$

Plane distance is given by:

$$L = [(E_2 - E_1)^2 + (N_2 - N_1)^2]^{1/2}$$

and the ellipsoidal distance by:

$$s = L/K$$

14. Computation of Standard Error Ellipses

From equation (11)

$$X = ((A^T P A)^{-1} \cdot A^T P) \cdot K$$

$$\sigma^2_X = ((A^T P A)^{-1} \cdot A^T P) \sigma^2_K ((A^T P A)^{-1} \cdot A^T P)^T$$

since $\sigma^2_K = \sigma^2_0 \cdot P^{-1}$ where σ^2_0 is the variance factor

$$\sigma^2_X = \sigma^2_0 ((A^T P A)^{-1} \cdot A^T P) P^{-1} (A^T P A)^{-1} A^T P^T \dots\dots\dots(14)$$

Let $N = A^T P A$

$$\sigma^2_X = \sigma^2_0 (N^{-1} A^T P) P^{-1} (N^{-1} A^T P)^T$$

Since P and N^{-1} are symmetrical

$$\begin{aligned} \sigma^2_X &= \sigma^2_0 (N^{-1} A^T P P^{-1} P A N^{-1}) \\ &= \sigma^2_0 (N^{-1} N N^{-1}) \\ &= \sigma^2_0 N^{-1} \dots\dots\dots(15) \end{aligned}$$

It can be seen therefore, that the precision of the parameters, σ^2_X , can be obtained by inverting the matrix of normal equations and scaling the weight coefficients obtained by the variance factor σ^2_0 . The most convenient way of analysing the combinations of variances and co-

variances resulting from these calculations is by computing standard error ellipses for points and lines in the network.

The equation of the error ellipse in matrix notation can be written as

$$(X - U)^T (\sigma_X)^{-1} (X - U) = 1$$

where X is the matrix of coordinates and U is the matrix of mean values. In this case X and U are two-dimensional vectors and σ_X is the variance covariance matrix which is a square matrix of order two.

It can be shown that the major and minor axes of the ellipse can be calculated from the characteristic equation of the matrix σ_X .

$$\text{i.e. } (\sigma_E^2 - \lambda)(\sigma_N^2 - \lambda) - \sigma_{EN}^2 = 0$$

$$\text{or } \lambda^2 - (\sigma_E^2 + \sigma_N^2)\lambda + (\sigma_E^2 \sigma_N^2 - \sigma_{EN}^2) = 0 \dots \dots \dots (16)$$

The two values obtained for λ are the squares of the lengths of the semi axes. These two values are called the eigenvalues of the matrix. The orientation of the major axis in the direction of the eigenvector associated with the largest eigenvalue is given by:

$$\tan \theta = \frac{\lambda - \sigma_N^2}{\sigma_{EN}} = \frac{\sigma_{EN}}{\lambda - \sigma_E^2} \dots \dots \dots (17)$$

The two by two matrix, σ_X , can be selected using the appropriate rows and columns for the station under investigation from the matrix $(\sigma_0^2 \cdot N^{-1})$ for an absolute error ellipse. It can also be derived from matrices selected for two stations, which together with co-variances can be used to calculate a relative error ellipse for the two stations.

The values required for a relative ellipse are:

$$\sigma_{(E2-E1)}^2, \sigma_{(N2-N1)}^2 \text{ and } \sigma_{(E2-E1)(N2-N1)}$$

These are calculated using the following equations:

$$\sigma_{(E2-E1)}^2 = \sigma_{E2}^2 + \sigma_{E1}^2 - 2\sigma_{E2E1} \dots \dots \dots (18)$$

$$\sigma_{(N2-N1)}^2 = \sigma_{N2}^2 + \sigma_{N1}^2 - 2\sigma_{N2N1} \dots \dots \dots (19)$$

$$\sigma_{(E2-E1)(N2-N1)} = \sigma_{E2N2} + \sigma_{E1N1} - \sigma_{E2N1} - \sigma_{E1N2} \dots \dots \dots (20)$$

If these three values are used to form the matrix σ_X as above and processed in the same way, a relative ellipse for the two points having coordinates (E1,N1) and (E2,N2) is obtained.

In addition to the relative ellipse, the precision of the line joining the two points can be calculated for distance and bearing by rotating the ellipse coordinate system, firstly so that it has the same bearing as the line, the length of the semi-axis in this case representing the standard deviation of the length of the line and, secondly, so that it has an orientation perpendicular to the line, the semi-axis then representing the bearing of the line.

The formula used for this is:

$$\sigma_L^2 = \sigma_N^2 \cos^2 \theta + 2\sigma_{EN} \sin \theta \cos \theta + \sigma_E^2 \sin^2 \theta \dots\dots\dots (21)$$

where θ is the bearing of the line.

The two values of σ_L^2 are calculated using θ and $(\theta+90)$.

The value of σ_L^2 representing the bearing of the line can then be converted to seconds using the length of the line by the formula.

$$\sigma_\theta^2 = \rho^2 \cdot \sigma_L^2 / d^2 \dots\dots\dots (22)$$

where $\rho = 206265$

15. Ellipse Confidence Levels

The confidence level for a standard ellipse computed using the elements of the inverse matrix is 39%. For the output of ellipse information the semi-major axes of the ellipse are multiplied by the factor or 2.45. This converts the ellipse to a 95% confidence level.

16. Optimization of Networks

It can be seen from equation (15) that the precision of the parameters, σ_X^2 , is calculated from the matrices A and P only and is not related to the matrix of absolute terms, K. The analysis of precision of the network can be done therefore whether there are observed values or not, since the normal equations are formed from the observation equation coefficients, A, and the weight matrix, P. The matrix A is formed from the provisional coordinates of the stations and the matrix P is formed from the standard deviations of the observations so that the only data required for optimization are:

1. Provisional coordinates.
2. Intended Observations. The type of observation is indicated by using the required record type in which the stations involved and the standard deviations are entered. No value for the observations need be entered.
3. Error ellipse selections for any two stations in the network.

The accuracy of the ellipses depends mainly on a realistic estimate of the standard deviations of the observations and is not so dependent on the accuracy of the provisional coordinates.

Appendix B

Seven sample input files and a sample options file are shown in this appendix to illustrate the use of the specific record types for each type of data. The record type is identified using the first two positions in each data record or the first three positions in the station label format. The data in these sample files are for demonstration purposes only and are not meant to be of sufficient quality to give a good adjustment result. The data can be copied and pasted into a text file to create a HAVOC input file.

Sample Data File 1

```
0000000001111111112222222222333333333344444444445555555555666666666677777777  
123456789012345678901234567890123456789012345678901234567890123456789012345
```

Job Heading

```
92WAGGA WAGGA 1:25000  
92 HAVOC TEST DATA
```

Options

```
01 055          3      1          1      3
```

Station Data

```
10 001-610033.995 6045611.130 GRANITE  
10 004-619330.696 6018408.514 MANJAR  
10 002 611342.06 6023090.31 COWRA  
10 003 610816.00 6024458.80 COWRA PHOTO POINT  
10 005 625138.897 6021485.668 MANJAR PHOTO POINT  
10 006-635804.967 6017672.510 CABRAMURRA  
10 007 610088.827 6045645.819 GRANITE DCA TOWER  
10 008-616992.774 6032912.800 NURENMERENMONG  
10 009-609920.946 6003689.509 DARGAL  
10 010-622552.019 6010010.059 LETT  
10 011-624726.158 5998555.472 JAGUNGAL  
10 012-631921.083 6025671.188 SELWYN  
10 014-647600.954 6023687.113 GOORUDEE  
10 015-639592.815 6003040.884 ADAMINABY  
10 016-594629.316 6039490.584 TUMBARUMBA  
10 013-648909.494 6032393.439 NUNGAR
```

Direction Data

```
21 001 004 0000000.0 1.5  
21 001 002 0153239.8  
21 001 006 3361051.3
```

Start of second direction set

```
21 1001 004 0000000.0 2.5  
21 1001 007 2563304.5 5.0
```

Start of third direction set

```
21 2001 016 2473600.0 1.0  
21 2001 012 1313607.2 1.4  
21 2001 006 1363440.1 1.1
```


21	2001	008	1503243.8	1.6
21	2001	004	1602357.6	
21	2001	002	1755634.3	
21	2001	009	1792511.6	1.1
21	002	004	0000000.0	1.5
21	002	009	0634848.8	
21	002	007	2362647.4	
21	002	003	2183553.0	
21	1002	004	0000000.0	
21	1002	009	0634849.2	2.5
21	1002	001	2361810.5	1.5
21	004	006	0000000.0	
21	004	010	0662721.1	
21	004	011	0721407.9	
21	004	009	1200152.9	
21	004	007	2484205.6	
21	004	005	3293139.9	
21	006	001	0464514.1	
21	006	007	0465100.2	
21	006	012	0633228.6	
21	006	013	1310700.3	
21	006	014	1522526.5	
21	006	015	2545526.0	
21	006	011	2993155.3	
21	006	010	3292415.0	
21	009	008	0125216.1	1.6
21	009	004	0315126.8	
21	009	006	0605319.5	1.0
21	009	010	0624102.7	1.6
21	009	011	1082325.3	1.1
21	009	001	3592524.7	
21	009	002	0032722.1	1.6
21	009	016	3360822.4	1.1
21	016	001	0673600.0	1.0
21	016	008	1053933.1	1.6
21	016	002	1334336.7	
21	016	009	1560814.5	1.0

Distance Data

22	001	002	22564.390	1.5	3.0
22	002	003	1466.480		
22	004	002	9261.685		
22	004	005	6574.400		

Error Ellipse Selections

50	7	3
50	7	2
50	5	2
50	2	3
50	3	7

End of Data Record (optional)

99

Sample Data File 3

0000000001111111111222222222233333333333444444444455555555556666666666777777
123456789012345678901234567890123456789012345678901234567890123456789012345

92RESECTION TEST
92LABEL FORMAT DATA

Options

01 561 350 100 2 0.5

Station Data

stn*SSM2203	327882.349	1268920.063
stn*SSM2201	327692.432	1268701.763
stn*SSM2200	327772.649	1268657.671
stn*SSM10300	327668.021	1268404.074

Direction and Distance Data

dir	SSM47184	SSM2203	022	31	30.0	5.0
dis		SSM2203	283.66		1.0	5.0
dir		SSM2201	298	15	40.0	
dis		SSM2201	92.260			
dir		SSM2200	248	41	00.0	
dis		SSM2200	1.120			
dir		SSM10300	202	34	50.0	
dis		SSM10300	275.13			

99

Sample Data File 4

0000000001111111111222222222233333333333444444444455555555556666666666777777
123456789012345678901234567890123456789012345678901234567890123456789012345

92RESECTION TEST
92STATION LABEL FORMAT

Options

01 561 350 100 2

Station Data

stn*SSM2203	327882.349	1268920.063
stn*SSM2201	327692.432	1268701.763
stn*SSM2200	327772.649	1268657.671
stn*SSM10300	327668.021	1268404.074

Direction and distance data

dds	SSM47184	SSM2203	022	31	30.0	2.0	283.66	0.5	5.0
dds		SSM2201	298	15	40.0		92.260		
dds		SSM2200	248	41	00.0		1.120		
dds		SSM10300	202	34	50.0		275.13		

99

Sample Data File 5

000000000111111111122222222233333333334444444444555555555566666666667777777
123456789012345678901234567890123456789012345678901234567890123456789012345

Job Heading

92NEWCASTLE CADASTRAL TEST
92BEARING AND DISTANCE INPUT

Options

01 561 9999100 1 3 1.0

Station Data

10 39 *373303.958 1355165.697 PM 5634
10 40 *373238.925 1355030.401 PM 30031

Bearing Data

20 1 5 1064020 30.0

Bearing and Distance Data (First Bearing Set)

25S5	1	2764030	30.0	90.928	1.0	100.0100000
25 21	37	1872030		30.618		
25 21	5	0072030		37.256		
25 37	27	2764900		24.583		
25 27	26			2.756		
25 26	25			29.501		
25 25	24			34.038		
25 24	12	0072000		30.316		
25 12	1			37.317		
25 12	13	0973530		22.732		
25 13	14	0072000		0.382		
25 14	16	0963730		25.146		
25 16	17			15.409		
25 17	18			2.756		
25 18	21			24.861		
25 17	26	1864900		30.537		

Bearing and Distance Data (Second Bearing Set)

25S21	39	0152830		118.68		0100000
25 37	21	0065640		30.59		
25 37	26	2762100		27.44		
25 26	25			29.425		
25 25	22	0062320		23.83		
25 22	23	0964120		14.08		
25 23	41	1863300		0.230		
25 41	42	0960200		13.93		
25 42	43	1451300		2.235		
25 43	26	1863200		21.91		
25 16	23	1863300		6.865		
25 37	40	2685200		4.15		
25 25	24	2762100		-1.0		

End of Data Record

99

Sample Data File 6

000000000111111111122222222223333333333444444444455555555556666666666777777
123456789012345678901234567890123456789012345678901234567890123456789012345

Job Heading

92NEWCASTLE CADASTRAL TEST
92BEARING AND DISTANCE INPUT

Options

01 561 9999100 1 3 2 1.0

Station Data

grd-PM 5634 PM 5634 373303.958 1355165.697
grd-PM 30031 PM 30031 373238.925 1355030.401

Bearing Data

brg 1 5 1064020

Bearing and Distance Data (First Bearing Set)

bdsS	5	1	2764030	30.0	90.928	1.0	100.	0100000
bds	21	31	1872030		30.618			
bds		5	0072030		37.256			
bds	31	27	2764900		24.583			
bds	27	26			2.756			
bds	26	25			29.501			
bds	25	24			34.038			
bds	24	12	0072000		30.316			
bds	12	1			37.317			
bds		13	0973530		22.732			
bds	13	14	0072000		0.382			
bds	14	16	0963730		25.146			
bds	16	17			15.409			
bds	17	18			2.756			
bds	18	21			24.861			
bds	17	26	1864900		30.537			

Bearing and Distance Data (Second Bearing Set)

bdsS	21	PM 5634	0152830		118.68			0100000
bds	31	21	0065640		30.59			
bds		26	2762100		27.44			
bds	26	25			29.425			
bds	25	22	0062320		23.83			
bds	22	23	0964120		14.08			
bds	23	41	1863300		0.230			
bds	41	42	0960200		13.93			
bds	42	43	1451300		2.235			
bds	43	26	1863200		21.91			
bds	16	23	1863300		6.865			
bds	31	PM 30031	2685200		4.15			
bds	25	24	2762100		-1.0			
99								

Sample Data File 7

Job Heading

92NULLA NULLA TEST

01 55

1

3

Geographical Coordinates

geo*207700340	LADY FRANKLIN	-36 06 26.48714	146 43 51.09141	546.733
geo*396700490	YARRAWONGA	-36 00 58.14744	145 59 58.45885	158.301
geo*299600200	RUTHERKNOLL	-36 04 33.86835	146 26 56.68611	212.406
geo*221400180	BOWEYA	-36 14 52.39673	146 05 35.87789	280.000
geo TS3564	NULLA NULLA	-35 56 40.19021	146 20 53.08301	202.670

Grid Coordinates

grd*TS7275-1	GOOMBARGANA	462978.944	6046799.001	404.745
grd*TS10595	COROWA SILO	445132.598	6016948.535	184.435
grd*TS2880	LOKA	506035.080	6031042.981	668.181
grd*TS2521	HOWLONG	467379.402	6025558.173	277.176
grd*TS6923	BOOMANOOMANA P	399988.379	6025414.059	250.766

Directions

dir TS7275-1	TS2880	S	0 0 0.0	1.1
dir TS7275-1	TS2521		58 11 45.8	1.1
dir TS7275-1	TS3564		111 12 4.1	1.1
dir TS7275-1	TS3564	S	0 0 0.0	0.7
dir TS7275-1	TS6923		29 56 52.9	0.7
dir TS2521	207700340	S	0 0 0.0	0.8
dir TS2521	TS3564		103 39 45.6	0.8
dir TS2521	299600200	S	0 0 0.0	0.7
dir TS2521	TS3564		39 4 45.6	0.7
dir TS2521	TS2880	S	0 0 0.0	1.1
dir TS2521	TS3564		180 21 33.4	1.1
dir TS2521	TS7275-1		266 22 13.9	1.1
dir TS2521	TS3564	S	0 0 0.0	1.1
dir TS2521	TS7275-1		86 0 40.4	1.1
dir TS6923	TS7275-1	S	0 0 0.0	0.8
dir TS6923	TS3564		23 28 25.0	0.8
dir TS6923	TS3564	S	0 0 0.0	0.7
dir TS6923	221400180		58 48 16.2	0.7
dir TS6923	TS3564	S	0 0 0.0	0.7
dir TS6923	396700490		44 57 0.6	0.7
dir TS6923	TS3564	S	0 0 0.0	0.8
dir TS6923	TS7275-1		336 31 34.0	0.8
dir TS3564	221400180	S	0 0 0.0	0.7
dir TS3564	396700490		41 30 2.8	0.7
dir TS3564	221400180	S	0 0 0.0	0.7
dir TS3564	TS6923		60 54 4.0	0.7
dir TS3564	396700490	S	0 0 0.0	0.7
dir TS3564	TS6923		19 24 3.0	0.7
dir TS3564	TS7275-1	S	0 0 0.0	0.8
dir TS3564	TS6923		233 25 13.6	0.8
dir TS3564	TS7275-1	S	0 0 0.0	1.1
dir TS3564	TS2521		40 59 3.4	1.1
dir TS3564	TS6923		233 25 15.8	1.1
dir TS3564	TS2521	S	0 0 0.0	0.7
dir TS3564	299600200		65 24 45.9	0.7

dir	221400180	396700490	S	0	0	0.0	0.7
dir	221400180	TS3564		52	32	38.2	0.7
dir	221400180	TS6923	S	0	0	0.0	0.7
dir	221400180	TS3564		60	17	41.6	0.7
dir	221400180	TS3564	S	0	0	0.0	0.7
dir	221400180	299600200		24	58	42.1	0.7
dir	299600200	221400180	S	0	0	0.0	0.7
dir	299600200	TS3564		88	54	0.3	0.7
dir	299600200	TS3564	S	0	0	0.0	0.7
dir	299600200	TS2521		75	30	28.2	0.7
dir	396700490	TS6923	S	0	0	0.0	0.7
dir	396700490	TS3564		115	38	58.3	0.7
dir	396700490	TS3564	S	0	0	0.0	0.7
dir	396700490	221400180		85	57	22.9	0.7

Distances

dis	221400180	TS3564	40741.496	2.0	4.0	S
dis	299600200	TS3564	17207.028			
dis	396700490	TS3564	32421.384			
dis	TS6923	TS3564	41369.314			

GPS Baselines

ccd	TS3564	TS10595	341.9287	-4910.2721	-4108.7784
ccd	TS3564	TS10595	341.9205	-4910.2681	-4108.7835

Sample Option File (HAVOC.OPT)

```
01          4000100          1          1 1
data files=c:\data
input files=a:
output files=c:\results
work files=e:
```


Appendix C

Bearing and Distance Adjustments

In 1989, while testing the feasibility of adjusting bearing and distance data from deposited plans, HAVOC was modified so that it could solve for rotation parameters. This was done by including in the mathematical model a rotation parameter for sets of bearings. When required an orientation parameter can be assigned to each plan so that, during the least squares adjustment, the plan data will be mathematically rotated to fit adjoining plan data.

This is necessary for DP data because the azimuths used for cadastral plans are derived from a variety of sources and epochs. When plans have to be fitted together to form a homogeneous set of spatial data, some or all sets of bearings have to be rotated so that they are all related to a common azimuth.

The program has been used for many years to process data from DPs to compute coordinates for survey marks connected to the cadastral fabric. The coordinates obtained are entered in the SCIMS database with other station information.

To enter data for this specific application, an extract of the input record formats is shown below. This describes the most commonly used input data obtained from deposited plans. Other record types from the complete set of input formats in Section 3 can be included if required. Other options described in Section 3.1.2.3 can be used if required.

1. Adjustment Description Record (92)

Column 1-2 Record Type = 92

Column 3-50 Adjustment description of up to 68 characters

There may be either 1 or 2 of these records if a heading is required, and they must be the first records in the file. The text entered on this record will be included in the heading on each page of the output file. This record can be omitted if a heading of this type is not required in the output file.

2. Option Record (01)

Column 1-2 Record Type = 01

Column 4-6 Zone number of the grid used for the adjustment. For MGA94 a prefix is included to identify the ellipsoid. This field can be left blank if station data is read from a SCIMS file. The zone is read from the SCIMS file and assumed to be MGA94

The value must be in the range

10 – 60 for MGA/GDA94
542 - 562 for ISG
649 – 657 for AMG/AGD66

801 - 860 for MGA/GDA94

These columns should be left blank for an adjustment on a local grid.

Column 8	Request for suppression of arc-to-chord and line scale factor reductions. If no reductions are required, enter the character 'N'. By default these reductions are applied.
Column 12-15	Limit in minutes of arc for the difference between the computed and observed values of a direction or azimuth observation. Default value is 25 minutes. Maximum is 9999 minutes.
Column 16-18	Limit in metres for the difference between the computed and observed values of a distance observation. Default value is 10. Maximum is 400.
Column 29	A number entered in this column is used to select the largest order required for stations from a SCIMS file to be held fixed in the adjustment. The default value is 2.
Column 48	<p>The character '1' can be entered to obtain a station summary for each station in the adjustment.</p> <p>The character '2' can be entered to obtain station summaries showing additional information related to the azimuth and distance between stations. This option can also be used to obtain ISG station summaries.</p>
Column 54	<p>Stage of processing required.</p> <ol style="list-style-type: none">1 data checking phase2 adjustment3 adjustment with output of geographical information4 creation of a file of adjusted coordinate values after adjustment
Column 56	<p>The character '1' can be entered to obtain a file of station information either before or after the adjustment.</p> <p>This file is named using the input file name with the extension '.stn' and has the same format as the station records used as input for an adjustment.</p> <p>If the character '3' is entered the station file created is inserted in the input file. The original file is saved with the extension '.cpy'.</p>
Column 58	Number of iterations required for the adjustment. Default value is 1.
Column 64	<p>Precision analysis processing required. If the calculation of error ellipses is requested the normal matrix has to be inverted. For large networks this will increase the processing time.</p> <p>Blank adjustment only.</p>

- 1 relative error ellipses after adjustment.
- 2 relative and point ellipses after adjustment.

Column 68-71 Centering standard deviation in centimetres. This value represents the combined centering standard deviation for both ends of the line. It is applied to the standard deviations of all azimuth, bearing and direction observations except where requested in the observation record.

Column 72-76 Factor used to reduce all observed distances before processing. The value is in the form of parts per million and can be used for a scale correction to all distances to allow for geoid-ellipsoid separation. It can also be used to enter a scale correction to be applied to all distances for reduction to sea level.

The character 'H' or 'h' can be placed in column 72 to request that the average height of the network be used to calculate a scale factor for reduction of distances to sea level. The scale factor determined using the 'h' character will not be applied to slope, horizontal or ellipsoidal distances.

3. Station Record (Grid Coordinates)

If station information is not entered the program searches for it in external files if they are available. This process is explained in Section 3.1.4.3.

- Column 1-3 Record Type = 'stn'
- Column 4 Station status. Blank for an unfixed station. '*' for a fixed station.
- Column 5-16 Station label.
- Column 18-37 Station name.
- Column 38-48 Easting coordinate. If coordinate fields are blank, coordinates will be sought in station data files or computed by the program.
- Column 49-59 Northing coordinate.
- Column 61-68 Station height in metres. Default height type is orthometric. (Optional. See Section 2.2.5)

4. Observed Distance Record

- .Column 1-3 Record type = 'dis'
- Column 5-16 Occupied station label.
- Column 19-30 Observed station label.

Column 33-43	Observed distance.
Column 45-48	Standard deviation in centimetres (constant). The default value is 10.0 centimetres.
Column 50-53	Standard deviation (parts per million). The default value is 0.0 ppm.
Column 64	Type of distance indicator. Distances are converted to mean sea level and then to the ellipsoid if requested. (see Section 2.27)
	'S' indicates a slope or spatial distance.
	'H' indicates a horizontal distance at the height of the occupied station.
	'G' indicates a geoidal or mean sea level distance. This is the default type.
	'E' indicates an ellipsoidal distance.
	'P' indicates a plane distance.
	'I' indicates an ISG projected distance.

5. Bearing and Distance Record

Column 1-3	Record type = 'bds'
Column 4	'S' indicates the start of a bearing set. 'E' indicates the end of a bearing set.
Column 5-16	Occupied station label.
Column 19-30	Observed station label.
Column 32	The character 'I' can be entered to indicate that the value entered is an ISG plane bearing. This is converted to an azimuth before processing. To indicate the end of a group of records with a default 'I' indicator the character 'B' can be entered to indicate the beginning of a different type of azimuth.
Column 33-35	Bearing - degrees.
Column 37-38	Bearing - minutes.
Column 40-43	Bearing - seconds. If left blank the previous bearing value will be used.
Column 45-48	Standard deviation of bearing. This can be entered as a negative value to suppress the application of the centering standard deviation. The default value is 1.0 seconds.

Column 50-58	Distance. If left blank the previous distance value will be used. If there is no distance available a negative value can be entered to indicate this. The entry of the characters 'NA' or 'na' can also be used to indicate that there is no distance available.
Column 59	Type of distance indicator as in distance record.
Column 60-63	Standard deviation in centimetres (constant). The default value is 10.0 centimetres.
Column 65-68	Standard deviation (parts per million). The default value is 0.0 ppm.
Column 70-72	Provisional set orientation - degrees.
Column 73-74	Provisional set orientation - minutes.
Column 75-79	Provisional set orientation - seconds.

6. Bearing Set Record

Another way of indicating the start of a bearing set is to use a bearing set record. This record allows the set to be given a name or identifier and also a different centering standard deviation. This record is optional.

Column 1-4	Record type = 'bset'
Column 6-8	Provisional orientation. Degrees
Column 9-10	Minutes
Column 11-14	Seconds
Column 16-35	Name associated with set if required.
Column 37-40	Centering standard deviation for set bearings in centimeters.

7. Text Records

Text records can be included anywhere in the file to describe or comment on the data. As long as the first three characters do not match an observation record type, text records will be ignored. Comments can be entered in any data record if the text is preceded by the character '!'.

Appendix D

Geodetic Test Data

The following data can be used for testing the Stage 1 geodetic computations of the program. A variety of data types have been selected from the results of the GDA94 national adjustment. The data has been extracted from the NEWGAN output files. The residuals produced from HAVOC can be compared with those of NEWGAN. The NEWGAN residual values are shown in the input file. For this comparison all stations are held fixed. The data can be copied and pasted into a text file to create a HAVOC input file.

92 GEODETIC DATA FROM NEWGAN OUTPUT FILES

01	56		3	2	1	2		3		
geo*PM31296			-32	44	13.54856	148	11	29.66498	272.401	23.77
geo*TS3687	PEAK HILL		-32	43	14.96357	148	11	51.59517	349.257	23.82
geo*TS5270	DUBBO		-32	14	16.87906	148	34	44.83225	316.941	25.27
geo*TS6689	SAPPA BULGA		-32	20	41.93969	148	22	53.91723	544.270	24.81
geo*PM85635			-32	06	43.46537	149	50	33.56084	427.382	27.66
geo*PM85633			-32	02	43.86924	149	45	55.34476	458.185	27.72
geo*TS7399	MATHER		-33	55	08.05618	151	13	52.16490	65.506	22.48
geo*TS7399-1	MATHER		-33	55	08.05617	151	13	52.16497	65.530	22.48
geo*TS10951-1	RTA ROSEBERY		-33	54	49.82677	151	12	18.29252	60.704	22.52
geo*TS4546	VINCENT		-32	55	36.34480	151	30	17.40168	426.393	25.81
geo*TS666	AWABA		-33	01	5.92007	151	33	5.31896	117.284	25.51
geo*TS2480	HIGHEST POINT		-34	32	8.60540	149	26	13.70335	1011.502	22.06
geo*TS2917	MCALISTER		-34	26	56.79826	149	45	10.46279	1033.796	22.89
geo*SS64865			-33	6	27.89669	147	48	10.11933	233.269	21.83
geo*SS64864			-33	6	29.54181	147	47	48.10286	233.755	21.82
geo*TS5821	CROWDY		-31	50	36.58470	152	45	12.34360	54.540	29.50
geo*TS6773	WOOLI		-29	51	42.31401	153	16	4.56872	11.301	34.92
geo*TS5829	YARIC		-32	21	38.17194	152	31	47.68930	216.102	27.38
geo*TS5476	CRAWNEY		-31	35	14.32013	150	59	37.09831	1446.521	30.82
geo*TS7124-3	PIALLAWAY		-31	7	23.14151	150	36	30.54166	929.503	31.18
geo*TS6305	BANDA BANDA		-31	9	34.05751	152	26	19.23870	1260.100	31.28
geo*TS5544	KULLATINE		-31	4	19.54936	152	39	56.71472	386.399	30.77
geo*TS5545	LAURIETON		-31	38	51.00499	152	50	25.35586	79.070	29.98
geo*TS5527	CAMDEN HAVEN		-31	39	34.21377	152	46	46.51135	489.798	29.89
geo*TS2671	KAUTHI		-31	45	02.91533	151	52	52.46627	435.100	30.17
geo*TS4548	VINEGAR		-31	47	37.18507	151	51	55.40699	743.500	29.99
geo*TS6218	BOGGABILLA		-28	36	00.11939	150	21	06.60510	220.339	35.30
geo*TS7225	BOGGABILLA SILO		-28	36	24.25189	150	21	21.26844	266.483	35.27
geo*TS5628-3	MOOMBIL		-30	19	02.18440	152	51	34.91083	1039.790	34.26
geo*TS5628	MOOMBIL		-30	19	02.31882	152	51	35.05636	1041.550	34.26
geo*TS653	ASHFIELD		-33	53	56.80575	151	7	28.42312	82.790	22.58
geo*TS4516-1	UNIVERSITY OF NSW		-33	55	05.71343	151	13	57.41890	85.046	22.48
geo*TS4138	LA PEROUSE		-33	59	04.92327	151	14	25.11772	65.200	22.22
geo*TS2771	KURNELL		-34	00	53.02683	151	13	32.94008	57.020	22.08
geo*TS1377	CANARYS		-33	55	54.18976	151	04	31.56156	87.300	22.47
geo*TS6035	DULABREE		-33	10	02.54875	149	50	11.55603	1184.276	26.42
geo*TS7138	GENOWLAN		-33	07	09.44437	150	03	22.97601	1039.658	26.23
geo*TS7374	FLAG		-34	27	57.57857	150	51	05.54610	52.540	21.13
geo*TS4858	WORONORA		-34	06	59.38670	150	57	08.11824	281.723	22.06
geo*TS4490	TYRAMAN		-32	29	11.61820	151	28	36.39787	563.510	27.32
geo*TS5518	CORICUDGY		-32	49	33.59216	150	21	03.20907	1259.698	26.63
geo*TS2761	KOSCIUSKO		-36	27	20.99907	148	15	48.58883	2230.289	16.33
geo*TS7278	BATEMANS BAY		-35	42	10.28359	150	10	36.55918	2.084	16.62
geo*TS7273	EDEN BREAKWATER		-37	04	27.40104	149	54	28.50180	5.436	11.84
geo*TS6041	MOORONG		-35	06	51.91072	147	18	15.57864	297.944	14.26

Directions		NEWGAN residual						
dir	TS7399	TS653	0	00	0.0	2.0	!	-0.51
dir		TS4516-1	139	20	9.4	5.0	!	-1.62
dir		TS4138	250	51	54.3	2.0	!	-1.17
dir		TS2771	260	7	55.0	2.0	!	1.49
dir		TS1377	341	47	38.0	2.0	!	0.45

Distances									
dis	TS5829	TS5821	61100.751				S	!	0.014
dis	TS5476	TS7124-3	63197.547				S	!	-0.029
dis	TS6305	TS5544	23746.910				S	!	-0.040
dis	TS5545	TS5527	5931.866				S	!	0.002
dis	TS2671	TS4548	4993.202				S	!	-0.008
dis	TS6218	TS7225	844.308				S	!	0.005
dis	TS5628-3	TS5628	5.946				S	!	0.000
dis	TS4516-1	TS7399	154.304				S	!	-0.009
dis	TS4490	TS5518	112147.394				S	!	0.055

Cartesian Coordinate Differences								
ccd	PM31296	TS3687	-1185.236	63.079	1476.712		!	0.001
								0.000
								0.000
ccd	TS5270	TS6689	14963.594	12644.991	-10148.623		!	0.006
								0.009
								0.000
ccd	PM85635	PM85633	259.571	8291.434	6237.373		!	0.001
								0.003
								0.001
ccd	TS7399-1	TS10951-1	889.819	2262.467	468.783		!	0.000
								0.000
								-0.002
ccd	TS4546	TS666	3006.983	-6591.270	-8349.771		!	0.002
								0.002
								0.001
ccd	TS2480	TS2917	-19390.783	-22254.086	7907.211		!	-0.003
								0.000
								0.001
ccd	SS64865	SS64864	327.291	468.510	-42.711		!	0.000
								0.000
								0.000
ccd	TS5821	TS6773	-122699.9637270	0.015	188630.276		!	-0.027
								-0.002
								-0.037
ccd	TS6035	TS7138	-12693.292	-16357.184	4545.245		!	-0.007
								-0.008
								-0.004
ccd	TS7374	TS4858	-23761.758	2612.393	31901.581		!	0.020
								-0.028
								0.011
ccd	TS7278	TS2761	128929.736	123820.850	-68849.346		!	0.060
								0.165
								0.075
ccd	TS2761	TS7273	-38663.512	-148002.973	-53655.182		!	0.029
								0.144
								0.123
ccd	TS6041	TS2761	26080.894	-118942.334	-121891.099		!	-0.065
								-0.302
								-0.117

The following data set obtained from the Geodetic Datum of Australia Technical Manual can be used to test the computations used for the projection of coordinate and observation data.

92 Test Data from GDA Technical Manual

01 55	1	2	3	
geo smeaton	-37 17	49.73137	143 59	03.16717
geo buninyong	-37 39	10.15611	143 55	35.38393
geo flinderspeak	-37 57	03.72030	144 25	29.52442
geo bellarine	-38 09	05.22718	144 36	43.67715
geo arthurs seat	-38 21	13.12687	144 57	02.55485
dis smeaton		buninyong		
dis buninyong		flinderspeak		
dis flinderspeak		bellarine		
dis bellarine		arthurs seat		

Appendix E

Data Analysis Programs

Several programs are available for the manipulation and analysis of HAVOC input and output files. These are described in this section of the documentation.

HAVOCSRT

This program reads an input file and sorts the station numbers and names. The sorted information is written to an output file. It can be used for the station number format only. It is useful for large files to determine the largest number used. This number has to be known for the merging of data sets.

HAVOCNUM

This program will read an input file and change the numbers of all stations in station records and observation records so that the numbers used are sequential numbers starting at number 1. It can be used for station number format files only.

HAVOCMRG

This program was written to combine a number of HAVOC data sets to create a larger adjustment data set. The program does this by renumbering the stations in station records and observation records to ensure that unique numbers are used. A separate documentation is available for the program.

HAVOCCON

This program will convert an input file from the station number format to the station label format and vice versa. When converting to the station label format the name field of the station record is used to create the station label.

HAVOCEXT

This program extracts data from a 132 column output file to create an 80 column extract file. The HP and NT versions of HAVOC have this function included as an option. This program has been included in later versions of HAVOC and can be selected using the option provided in the option record. More development is needed to cater for all output options.

HAVOCDST

This program reads coordinate files produced by HAVOC and computes the distance between every point in the adjustment. It uses an input distance value to create an output file of distances

shorter than the supplied value. This can be used to find the accidental entry of a station with two or more different labels. This program has been included in later versions of HAVOC to produce distance information in the adjustment report file.

Appendix F

HAVOC Version 4.2

This version of the program was developed for testing the reliability of a least squares network adjustment using observation residuals, redundancy numbers and marginally detectable errors. In this version the Cholesky banded matrix solution and inversion algorithm has been replaced by basic matrix product and inversion algorithms operating in computer memory. This has been useful for comparing the results of the two different matrix processing algorithms. The results obtained are exactly the same as those from other versions of the program.

The program code used for all matrix processing in this version of HAVOC, and also the program ORCA, was extracted from the program EDMCAL which also provides the analysis of residuals using the reliability techniques of Baarda. The advantage of using these algorithms is that the full matrix is stored so correlation values can be easily included when required. Also the program code for the many matrix arithmetic operations is more easily read and modified than the other versions of HAVOC. The disadvantage is that the computation is slower especially as the number of observations becomes large. The current version of the program has an adjustment size limit of 1000 stations and 6000 observations.

This program will process the usual input files but it is able to produce additional information and use a different form of processing for GPS baselines. Additional functions are described below.

Projection

The program currently uses only the GDA94 datum and MGA projection. It does not have the AGD66 and ISG options available. In the option record only the MGA zone needs to be entered.

GPS Baselines

This form of data entered in "ccd" records can still be converted to bearings and either ellipsoidal or spatial distances as in Version 3.6. In Version 4.2 GPS baselines can also be converted into grid differences in easting and northing values. With this data the three dimensional cartesian coordinate variance covariance matrix or correlation matrix can be entered.

This is converted using a Jacobian matrix into a correlation matrix for the difference in easting and northing values. The processing of this form of baseline data is more rigorous because correlations are used in the adjustment.

The option for processing baselines in this way can be selected by entering the number 4 in column 38 of the option record.

Observation Redundancy Analysis Output

The output of observation redundancy numbers and marginally detectable errors can be obtained by entering the number 1 or 2 in column 52 of the option record. This output is formatted in the same way as the output from the program ORCA. Details about the values shown in the output can be found in the ORCA documentation.

This information is provided in a file of redundancy analysis information with the name based on the input file name with the extension '.red'. If the option '2' is selected the external reliability is included in the output file. This can be used to determine the effects on the station coordinates of an error equal to the marginally detectable error occurring in each observation.

Option Record

Most of the options available are the same as version 3.6 however there are some related to the additional functions of the program.

Column 4-6 The zone must be an MGA value.

Column 38 The value '4' can be entered to select the conversion of GPS baselines to easting and northing differences.

The value '5' can be entered for the conversion above with the diagonal terms of the rotated correlation matrices being replaced with a standard deviation computed using the constant and ppm values entered in the "ccd" record.

Column 52 The value '1' can be entered to obtain the redundancy report. This will be a file with the extension '.red'.

The value '2' can be entered to obtain the external reliability matrix in the redundancy report.

VCV Matrix Input

The VCV matrix for a baseline can be entered immediately following the baseline coordinate difference components. The six terms of the upper triangular part of the matrix must be entered in row order. The 12 character matrix term fields start in columns 5,18,31,44,57 and 70. The following data demonstrates the format for this type of input.

```
ccd TS-10565 PM-70940 -794.678 -765.925 312.433
vcv 0.00003969 -0.00002979 0.00002319 0.00003969 -0.00002095 0.00003969
```

```
ccd TS-10565 PM-24316 -196.523 -639.710 -268.899
vcv 0.00003136 -0.00002396 0.00002019 0.00003136 -0.00002030 0.00003844
```

```
ccd PM-70940 PM-24316 598.158 126.211 -581.329
vcv 0.00003136 -0.00002580 0.00002000 0.00003721 -0.00002144 0.00003721
```

```

ccd TS-10565    PM-24322    -5.892    -1037.974 -799.419
vcv 0.00005041 -0.00003202 0.00002649 0.00003721 -0.00001957 0.00003721

```

Matrix input can also be in the exponent form such as the following.

```

ccd SS149879    PM20013      357.782  656.446  2.266  0.4 2.0
vcv 0.10550E-04 -0.43000E-05 0.59300E-05 0.45300E-05 -0.27100E-05 0.64300E-05

```

```

ccd SS112346    SS149879      360.167  373.041 -195.634
vcv 0.39500E-05 -0.17900E-05 0.17300E-05 0.19900E-05 -0.72000E-06 0.29900E-05

```

```

ccd PM33378     SS149879     -367.606 -137.837  427.969
vcv 0.76200E-05 -0.38500E-05 0.43300E-05 0.48200E-05 -0.24400E-05 0.45500E-05

```

Correlation Matrix Input

The correlation matrix for a baseline can be entered immediately following the baseline data as shown in the following example. The diagonal terms are standard deviation values. These are terms 1,4 and 6 in the 'cor' line.

```

ccd NELG      _056      -10753.3450 2966.9130 14442.9970
cor .018      -.57      .66      .010      -.40      .014

```

```

ccd _056      _039      12251.5090-7512.1860 -19393.6110
cor .028      -.55      .71      .012      -.47      .020

```

```

ccd _BM2      NELG      9241.1490 759.4220 -10684.5230
cor .030      -.80      .39      .024      -.39      .014

```

```

ccd _BM2      _039      10739.2890-3785.8410 -15635.1410
cor .022      -.84      .66      .018      -.57      .012

```