User's Guide for the
Algorithm Testing System
Version 2.0

David A. Rosenfeld

NIST

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User's Guide for the ATS Version 2.0

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I. Introduction

The Algorithm Testing System (ATS) is a software system used for testing data analysis software typically found in Coordinate Measuring Systems (CMSs). The ATS is one of the tools used in NIST's Algorithm Testing and Evaluation Program for Coordinate Measuring Systems (ATEP-CMS)—a NIST Special Test Service for evaluating the performance of CMS data analysis software. (ATEP-CMS was recently approved as a NIST Special Test Service, numbers 1007OS and 1008OS.) The basic approach of ATEP-CMS is to compare fit results calculated by the software under test to fit results calculated by NIST. The ATS is used in ATEP-CMS to generate test data sets, generate NIST fit results, and compare the results.

The ATS provides a graphical interface, extensive on-line help, and graphical capabilities for viewing data sets and fit residuals. The subject of CMS software evaluation, however, is technical in nature. NIST therefore recommend that ATS users have a good understanding of coordinate metrology and CMS operation.

I.A How to Use this Guide

This User's Guide is written primarily as a means of getting started with the ATS. NIST strongly recommends that it be carefully read it in its entirety. Section II provides installation instructions. Section III provides general information about the ATS and defines some of its general concepts. Section IV is a hands-on tutorial which will train the user in many of the basic ATS capabilities. Beyond this, the ATS on-line help is very extensive. The user should find this sufficient for most of his help needs. The ATS graphical capabilities also allows the user to view what he is doing. For further details, the user is referred to the *Reference Manual for the ATS Version 2.0* (see below for complete bibliography). The *Reference Manual* is the companion volume to the User's Guide. It provides tables and information completely describing virtually all of the ATS capabilities, and is most useful for occasional look-up.

I.B Typefaces and Fonts Used in this Guide

ALL CAPS	Refers to the names of keystrokes, such as ENTER, INS, and DEL.
Italics	Refers to the names of ATS-named objects, such as one of the ATS windows, or a field of an ATS window.
"Helvetica Narrow"	This font is used to refer to the names of user-generated objects, such as experiments (default name, "new Experiment") and tests ("new Test"). Such names are typically entered by the user.

I.C Other Relevant Publications
        The following is a list of relevant publications and sources of information:

1. ATS on-line help.

2. Rosenfeld, David A., *Reference Manual for the ATS Version 2.0*, submitted to be a NISTIR, National Institute of Standards and Technology, Gaithersburg, MD.

3. Diaz, Cathleen, 1994, *Concept for an Algorithm Testing and Evaluation Program at NIST*, NISTIR 5366, National Institute of Standards and Technology, Gaithersburg, MD.

4. ASME, 1995, ASME B89.4.10-199x, *Methods for Performance Evaluation of Coordinate Measuring System Software*, Draft, American Society of Mechanical Engineers, New York.

        The ATS was developed in coordination with, and in support of, the ASME B89.4.10 draft standard, *Methods for Performance Evaluation of Coordinate Measuring System Software*.

I.D Contacts for Further Questions and Comments
        Further questions and comments, including the reporting of bugs, should be directed to any of the members of the ATEP-CMS project team at NIST. They are:

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II. Installation

This section provides installation instructions for the ATS. It also discusses upgrading ATS Version 1.1 data into Version 2.0 format.

II.A System Requirements
In order to run the ATS, you must have a PC-class computer. The minimum configuration necessary is as follows:

> 80286 or higher cpu
> DOS Version 3.3 or later
> Hard disk with at least 5 MB free space
> High-density 90 mm (3½ in) floppy drive
> 520 KB free memory

Optional equipment:

> 80x87 Math co-processor
> Mouse
> EGA or VGA graphics (necessary for graphics)
> Extended or expanded memory

A math co-processor is not required. However, the ATS will use one if it is present. A mouse is not required, but is highly recommended. To install the software as it is distributed, you must have a high-density 90 mm (3½ in) floppy drive. (Other formats are available upon request.)

II.B Installation
The ATS is distributed on a DOS-formatted disk. The ATS is distributed in compressed format, and the installation script found on the disk should be used to install the system. The file README.TXT found on the disk contains detailed installation instructions and last-minute changes to the documentation. It explains how to run the installation script and what changes the script will make to your computer.

You can view the README.TXT file using any text editor (like the EDIT command in DOS). The install script will place the following files in a directory of your choice (as described in the installation instructions):

> ats.exe - the ATS executable.
> ats.lnf - a collection of screen files for the ATS user interface.
> ats.hlp - the ATS on-line help file.
> ats.pif - a program information file ("pif") to run the ATS from MS Windows™ 3.1.

Other files may also be installed, depending on the release version of the ATS.

II.C Upgrading from Version 1.1

A translator program, the ATS Translator, was developed to allow users of ATS Version 1.1 to upgrade their output into Version 2.0 format. This program, together with documentation, is available upon request. It is not provided with the standard ATS package, since it is assumed that this program would not be required by the majority of Version 2 users. It should also be noted that the overall design of Version 1.1 is drastically different from that of Version 2. For this reason, not all test cases defined in Version 1.1 will translate into Version 2. In addition, minor bugs have been discovered in the previous release of Version 1.1. It is very possible that tests which were generated using Version 1.1 may be regenerated in Version 2 with slightly different results.

III. Overview

This section describes the overall purpose and functionality of the ATS, and introduces you to some of the basic concepts of its design. It assumes you are familiar with the subject of coordinate metrology. For more background on this subject, we recommend Phillips, S., 1995, *Performance Evaluations*, Coordinate Measuring Machines and Systems, ch. 7, pp. 137-226, Marcel Dekker, New York.

III.A Purpose, Functionality of the ATS

The ATS is a tool to help evaluate the performance of coordinate measuring system (CMS) data analysis software. CMS data analysis software translates data points collected by a CMS into a geometry description. It accomplishes this task using fitting routines, which finds the geometry that best fits the points. The ATS evaluates such software by comparing its fit results to reference fits, or fits which are considered "correct" for the analysis. The reference fits may be obtained from the ATS's own fitting routines, or may come from another source. The ATS provides the following basic capabilities to allow such software evaluation:

- generation of data sets, simulating a CMS gathering data points on a part;
- generation of reference fits, by fitting the data sets using ATS fitting routines;
- importing and exporting of data sets and fits;
- performance of analyses to compare fit results; and
- printing of information (to printer or file), both of ATS-generated objects, such as data sets and fits, and of ATS analyses. An analysis can be exported in a format suitable to be imported into a spreadsheet program.

III.B Typical Scenario

Using the above capabilities, you will be able to perform a complete performance evaluation of CMS software. In a typical scenario, you will execute the following steps:

1. define parameters for the data sets you would like generated;
2. generate the data sets, along with reference fits;
3. export the data sets to a floppy disk;
4. read the floppy disk and fit the data sets using the CMS software to be tested;
5. write the fit results back to a floppy disk;
6. import the test fits into the ATS;
7. compare the test fits to the ATS reference fits by performing an analysis; and
8. print a report of the analysis.

The tutorials of section IV will step you through this and other typical scenarios. The remainder of section III will introduce you to some of the basic concepts and terminology of the ATS.

III.C ATS Hierarchy

Data in the ATS is organized into a hierarchy according to the operational procedures of the ATS. The purpose of the hierarchical design is to organize the data in a logical fashion and to enforce sequential execution of commands depending on the availability of data. In general, you must define an object on a preceding hierarchical level before proceeding to the next level. The five levels of the ATS hierarchy form a tree structure. Thus, an object at a given level (unless it is at the highest) will have a single parent on the preceding level, and (unless it is at the lowest) may have a number of children at the next lower level. The levels of the ATS hierarchy, and the basic purpose of each, are described in the table below.

Level	Purpose	User Operations
Experiment	Container class for collection of tests for many geometries, typically comprising all the tests performed for a single CMS.	print
Geometry Type	Divides the tests of an experiment according to geometry.	analyze (all fits attached to current geometry), print
Test	Contains test cases for the geometry. Each test case defines information about the geometry. Using this information, multiple data sets can be generated or imported. The information described is the nominal geometry definitions, the form errors, the sampling plans, and the measurement errors.	define parameters of geometry, generate data sets (and fits), import & export data sets, analyze (all fits attached to current test), print
Data Set	Contains data sets generated from parent test, or imported and attached to parent test.	generate reference fits, import & export data sets and fits, analyze fits, print
Fit	Contains reference fits generated for the parent data set, along with test fits imported and attached to the parent data set.	import & export fits, print

III.D Data Generation

The ATS generates data sets by simulating a CMS taking measurements of a part. The simulation is controlled by four basic information classes that you must supply: The nominal geometry definition (its type and parameters), the form error(s), the sampling plan, and the measurement error. These are all described in detail in the *Reference Manual* (sections VI-IX). A brief summary is provided here.

Seven geometries are supported by the ATS:

- Lines (in three-dimension)
- Circles (in three-dimension)
- Planes

- Spheres
- Cylinders
- Cones
- Tori

The ATS supports form errors which approximate many typical manufacturing errors. Along a line, for example, the ATS can generate a random error, a sinusoidal oscillation, a step, and a bend. Similarly, in the surface of a plane, the ATS can generate a random error, sinusoidal waves, a step, and a bend. Different form errors are implemented for each geometry. For a complete listing, see the *Reference Manual*, section VII.

The ATS supports three types of sampling plans:

- Equispaced - points are sampled at equal intervals on the geometry.
- Stratified - the geometry is divided into a specified number of bins; random points are chosen within each bin.
- Random - points on geometry are sampled randomly.

The ATS supports two types of measurement errors. Measurement errors are propagated in a random direction in three dimensions.

- Uniform - Introduced into each data point is an error whose magnitude is a uniformly distributed random variable between zero and an amplitude value supplied by the user.
- Normal - Introduced into each data point is an error whose magnitude is a normally distributed (Gaussian) random variable with zero mean and standard deviation equal to the amplitude supplied by the user.

Each of these basic information classes are defined in the test description. Each of the above classes contains one or more *schemata*. A schema is a range of values for a variable. For example, if you were entering a circle definition, you could enter a range of radius values, such as five values between radius=1 and radius=5. This would result in the definition of five circles, of radii 1, 2, 3, 4, and 5 respectively. In general, you can define multiple cases of each of the four information classes above. The total number of cases which will be defined in a test description will be the product of the numbers of geometries, form errors, sampling plans, and measurement errors you define. This will be the number of data sets which can be generated from the test description.

IV. Tutorial

The following lessons are intended to provide you with a good working knowledge of the ATS. The lessons build on one another, and assume you are familiar with the information presented in the previous lessons. We therefore recommend following each lesson carefully, step by step. By the end, you should be able to use all of the major capabilities of the ATS.

These lessons were written with the intention that you would be running the ATS while studying these lessons. They were *not* written to be read alone. A few figures are provided, often to assist you in entering inputs into the ATS. For the most part, however, these lessons would be quite cryptic to a first-time user without a running ATS in front of him or her.

Lesson 1 - Getting Started

In this lesson you will become familiar with the basic appearance of the ATS and some of the common commands and hotkeys.

1

initializing the ATS

At the DOS prompt, type ATS[1].   To run the ATS, you must either be in the same directory as the ATS executable (ats.exe), specify the full pathname of ats.exe, or the directory of the ATS must be in your DOS PATH variable. The ATS will take a few seconds to initialize. A message will be displayed telling you what is going on. The first time you run the ATS, it will create and initialize the database. This will create a subdirectory, *"data"* in the directory in which the ATS is installed.

2

ATS screen

After initialization, a "data-less" ATS will appear before you. You will see the following, as illustrated in figure 1:

Menu Bar - across the top of the screen (most of which is disabled because there isn't much you can do with no data).

Status Button - in the upper right corner ("Ready").

Panels - The top third of the screen is divided into five panels. These correspond to the different levels of the ATS hierarchy. The purpose and function of each level will be explained fully in coming lessons.

Viewer - the bottom half of the screen displays further details about the ATS object you are dealing with.

Prompt Line - the bottom line of the screen displays some of the currently available hotkeys.

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[1] If you are running MS Windows™ 3.1, run the ats.pif file provided. As mentioned in section II, Installation, ATS is a DOS application, and an icon is not provided. You may, however, run it directly from Windows using the File-Run command of the Program Manager.
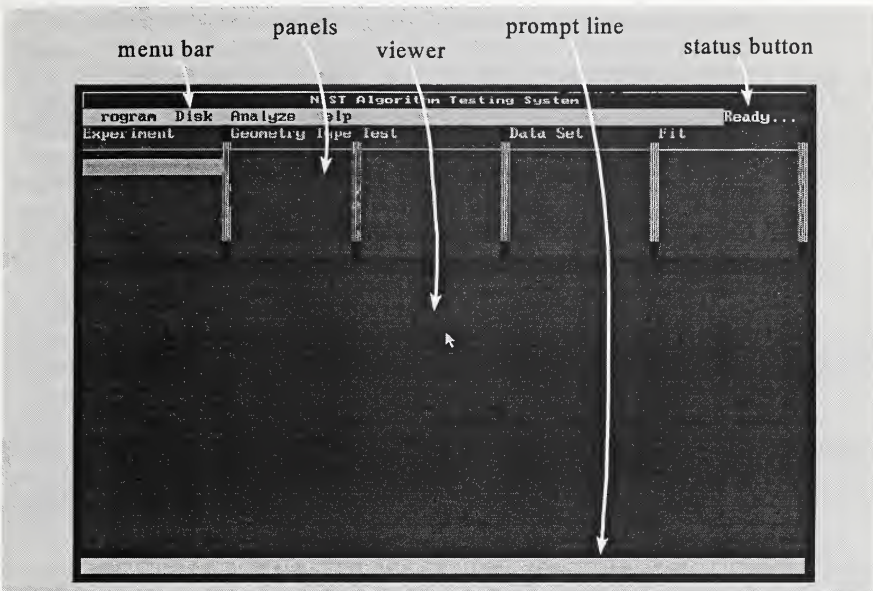
Figure 1 - The ATS Initial Screen

3
on-line help

Press F1 to activate the ATS on-line help. The on-line help is context sensitive. It offers help according to the current status of the ATS. Use the mouse or arrow keys followed by ENTER to select one of the highlighted help topics. Try selecting "Topics" and then "ATS Hierarchy" for some basic information. When finished, select "Exit Help" or press ESC to return to the ATS.

4
inserting an experiment

Assuming you have not yet used your copy of the ATS, you will see a blank shaded line in the experiment panel. If your PC supports color, the line will be light purple. "Experiment" is the highest level of the ATS hierarchy. The hierarchy defines the order in which operations can be performed in the ATS. Thus, an experiment must be defined before proceeding to further panels. (For this reason it is impossible to move to a further panel.) Press INS, numeric keypad '+' or double-click the shaded line with mouse to insert a new experiment.

5
inserting, selecting update viewer, load children

An experiment has now been inserted with default name "new Experiment". This inserted object is also the current <u>selected</u> object of the ATS. This is typical ATS behavior: When you insert an object, it is automatically selected. By selecting "new Experiment", two changes have occurred. First, the viewer now displays some infor-

mation relating to this new experiment. (In step 6 we will edit this information.) Second, the geometry panel fills up with the list of geometries the ATS supports. These geometries are the *children* objects of the *parent*, "new Experiment". (The geometries were created automatically by the ATS, since the geometry types supported by the ATS are predefined. It is therefore not necessary to explicitly insert geometry types as we inserted an experiment above.) In general, when you select (or insert) an ATS object, the following two changes occur: The viewer fills with information about the current object; and the ATS displays the children of that object in the next panel. The ATS also displays a "▸" next to the parent, showing that the next panel is displaying the parent's children.

6

viewer - editing name and comments

Press Alt+PgDn or use the mouse to move to the viewer. You can select the *"Experiment"* field to rename this experiment. However, in future lessons we will continue to refer to this experiment as "new Experiment", so leave the name unchanged. You can also select the *"Comment"* field (click the mouse to the right of the word "Comment", or move there with the arrow keys and press ENTER). This will open up a window in which you can add comments relating to this experiment. Add a short comment (of your choice). The ATS ignores both object names and comments. (It has its own identifiers for its internal bookkeeping.) Object names and comments are provided for user convenience only. Press Alt+PgUp or use the mouse to move back up to the experiment panel.

7

selecting a geometry

difference between selecting and inserting

Use the arrow keys, the tab key, or the mouse to move to the geometry (or geometry-type) panel. The geometry panel is displaying the children of "new Experiment", which are all the geometries the ATS supports. When we inserted "new Experiment", the geometries were created and stored in the database. None of the geometries, however, were loaded (from the database to local memory). Select a geometry by using the arrow keys to highlight any one and pressing ENTER, or place the mouse over a geometry and single-click. Recall that we <u>inserted</u> a new experiment in step 4 by pressing INS, keypad '+' or mouse <u>double</u>-click. Here we <u>select</u> an already-existing object by pressing ENTER or mouse <u>single</u>-click. Selecting an object <u>loads</u> an already-existing object from the database to local memory. Inserting an object creates a new one (with default contents) and places it both in the database and local memory.

8

geometries can't be inserted or deleted

Now that a geometry has been selected, the same changes occur in the ATS as we observed in step 5. The viewer now displays information regarding the selected geometry. You can move to the viewer to add comments. The name of the geometry itself, however, cannot be edited. Geometries also cannot be inserted or deleted. This information (i.e. the number and names of selectable geometries) is defined by the ATS. Note that the test panel did not fill with children of the selected geometry, as did the geometry panel when we inserted an experiment in step 5. This is because no tests yet exist for the current geometry. (Geometries, however, are predefined and

inserted automatically by the ATS as soon as an experiment is created, as above.)

9
loaded vs. highlighted

Use the arrow keys to move up and down the geometry panel. (Don't miss geometry type torus, which is below the visible portion of the panel.) Note that the last-selected geometry (and the experiment) is black on light gray. This signifies that the contents of that geometry are loaded from the database to local memory. The geometry selected with the arrow keys, or the <u>highlighted</u> object, (whether it's loaded or not) is white on purple.

10
ATS unloads automatically

Select a different geometry (mouse single-click or ENTER). Note that the previously-selected geometry is unloaded. At most one object can be loaded per level of the ATS hierarchy. There is no way to directly unload an object. You can, however, load a different object of the same level by selecting it. The ATS automatically unloads the previously-loaded object to make room for the new selection.

11
menu bar follows panel with highlight-ed object

Use the arrow keys to move back and forth between the experiment and geometry panels. Note that the menu bar changes. The menu bar displays the operations available to the objects in the panel which contains the <u>highlighted</u> object. This is the case even though the last-<u>selected</u> object (about which the viewer is displaying information) may not be in this panel. In general, ATS commands are performed on objects in the panel which contains the highlighted object. Within the panel, some commands affect the highlighted object while others affect the loaded object (if any), regardless of which object is highlighted. For a complete listing, see the *Reference Manual*, section IV.

12

can't select a blank line

Use the arrow keys to move back to the experiment panel. We are now going to insert and delete a second experiment. Use the arrow keys to move to the second line of the experiment panel, the blank line under "new Experiment". First, note that ENTER and mouse-clicks have no effect. Once again, this is because these commands select already-existing objects. There is not, however, anything to select on this blank line. Press INS, keypad '+', or double click the mouse to insert a second experiment. Its default name is also "new Experiment".

13

no need to save changes

Now that we have inserted a second experiment, the ATS unloaded the first experiment to make room for the second, as in step 10. It was not necessary for us to explicitly save our changes to the first experiment (we added a comment in step 6). The ATS never requires the saving of objects. Unless you delete an object, as soon as you unload it (by loading a different object or by exiting the ATS), the ATS saves its contents.

14
deleting an object - ATS

To delete the second experiment, use the arrow keys or mouse to highlight it (if it is not highlighted already), and press DEL or keypad '-'. The ATS will prompt you for

prompts for confirmation

confirmation. To confirm, mouse-click the *"ok"* button on the confirmation window, or press ENTER. The experiment will now be deleted. A deleted object is removed from local memory and from the database. Note that all the children of a deleted object (here the geometry objects) are deleted too.

15

Quitting the ATS

ATS prompts for confirm

Next we will move to the menu to exit. Press Alt+P (upper or lower case p) or use the mouse to select the *"Program"* section of the menu. You can also reach the *"Program"* section by pressing F10 to pass control to the menu, and pressing 'p' to select *"Program"*. Then press 'q' or use the mouse to select *"Quit"*. The ATS will prompt you for confirmation. Confirm by mouse-clicking the *"ok"* button or by pressing ENTER.

16

Alt+'letter', F10, call menu

ESC exits menu

Before moving on, let's review some of the menu-selection commands we have just learned. From elsewhere in the ATS, pressing the Alt key together with the first letter of a menu section will select that section of the menu. Pressing F10 will also pass control to the menu. When you are already in the menu, pressing the highlighted letter of a selectable menu choice (without the Alt key) selects that menu choice. Lastly, the ESC key exits the current level of the menu. It exits the menu altogether if you are at the highest menu level.

17

"data" directory

making backup directory

After exiting, view your current directory (or the directory in which ats.exe resides). You should see a subdirectory, *"data"*. This contains a number of files that make up the database. You may want to copy its contents into a backup directory (such as *"data.sav"*). By doing so, if you run into problems at a later time, you will be able to recopy this clean version of the database. This will avoid having to recreate the database. You may also want to use the backup to store good data that you don't want to risk losing.

Lesson 2 - Generating circles with sinusoidal form errors

In this lesson, you will learn the purpose and function of the different levels of the ATS hierarchy. You will also learn how to define tests and generate multiple data sets.

1
selecting "new Experiment"

Start the ATS. The experiment panel will display the list of existing experiments in the database. If you followed lesson 1, the only existing experiment is "new Experiment". It is not loaded from the database to local memory. The ATS merely displays it to inform you what exists in the database and what may be selected. Select it by pressing ENTER or clicking the mouse on it. "new Experiment" will be loaded from the database to local memory. As in lesson 1 (step 5), the viewer fills with information about the experiment. Also, the geometry panel displays the existing children of "new Experiment".

2
editing from lesson 1 saved

geometry selected in lesson 1 reloaded

Now that "new Experiment" has been loaded, you should note the following two details: First, if you look at the *"Comment"* field in the viewer, the comment you added in lesson 1 (step 6) is still there. This is, once again, because all insertions and editing you did in lesson 1 were saved automatically when you exited the ATS at the end of lesson 1. Second, one of the geometries is loaded (from the database to local memory), and is displayed in black on light gray. This is the geometry you selected in lesson 1, step 10. Whenever you select an ATS object, the ATS automatically reloads all the previously-loaded descendants of the object, all the way down the ATS hierarchy.

3
purpose of experiment and geometry levels

The experiment level of the ATS hierarchy serves as a container for an entire collection of tests. The geometry level divides your experiment according to geometry. Since we are generating data sets simulating circles, select "Circle" (if it is not selected already).

4
purpose of test level

Move over to the next panel, the test panel. At the test level, you define the actual parameters necessary to define a test case and generate data sets. As yet, there are no tests defined. Thus, this panel is highlighted, but empty. Press INS, keypad '+' or double-click with the mouse to insert a test. We now have a default test description for a circle. Its default name is "new Test" (look familiar?).

5

contents of test viewer

Press Alt+PgDn or use the mouse to move to the viewer. In the test viewer you will define the actual parameters of the test. There are also editable *"Test"* and *"Comments"* fields. Feel free to add comments, but do not edit the default name. We will be referring to this test as "new Test" for the remainder of these lessons. There are four test-specific fields. They are: *"Nominal geometries"*, *"Form errors"*, *"Sampling plans"*, and *"Measurement errors"*. To the right of each field name is a value which reflects the number of cases defined for each schema. The values next to the four fields above are 1, 1, 0, and 1 respectively. These are the numbers of cases defined

for each schema by default. Each schema will be examined more closely in the coming steps.

6
the "Edit Circle Schema" window

Select (mouse or ENTER) the *"Nominal geometries"* field. (Select to the right of the words "Nominal geometries", where the number 1 is displayed.) This will cause a new window, *"Edit Circle Schema"* to be displayed. In it you will define a set of circle definitions for which data sets will be generated.

7
schema - definition

In this window, you will be entering schemata, or ranges of values. For each geometric parameter displayed in the window, you may enter three values, *"initial value"*, *"limit value"* and *"# of values"*. If, for example, you enter 1 for your starting x location value, 5 for the limit value, and 3 for the # of values, you will be defining 3 circles with x locations starting at 1 and ending at 5. Their values will be 1, 3, and 5 respectively. The total number of circle geometries will equal the product of all the *"# of values"* in this window. If the # of values for a particular schema is set to 1, the limit value will be ignored.
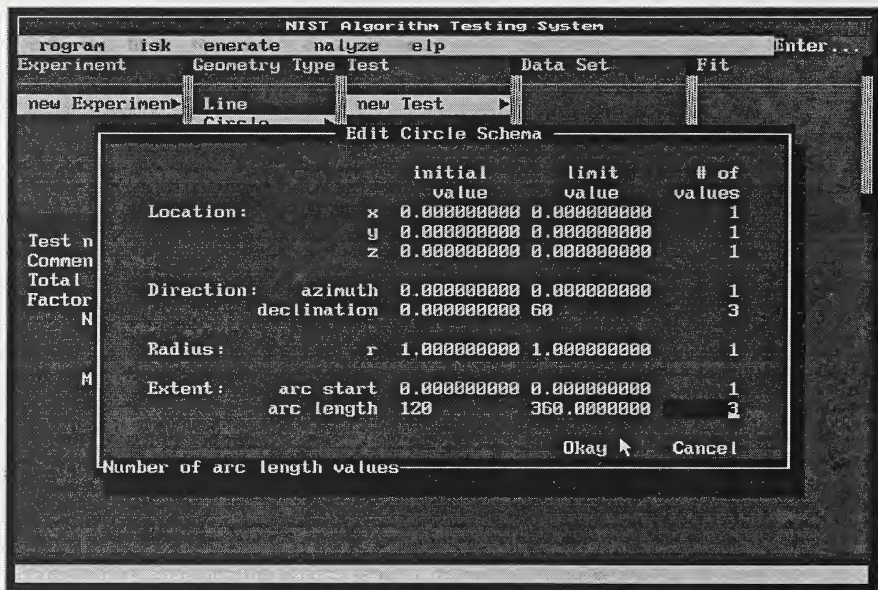

Figure 2 - The *"Edit Circle Geometry"* Window

8

editing the "Edit Circle Schema" window

As shown in figure 2, you can insert values for the location, direction, radius, and extent of the circle. The direction specifies the direction of the normal to the plane of the circle. It is represented by an azimuth, or angle (in degrees) from the global x^+, and declination, or polar angle from the global z^+. (For further details press F1 to see the on-line help.) Enter 60 for declination's limit value, and 3 for declination's # of values. This will result in 3 declination values - of 0 (the start value), 30, and 60. Enter 120 for arc length's initial value and 3 for its # of values. This will result in 3 arc lengths - of 120, 240, and 360. (The proper values to be entered are shown in figure 2.) The total number of nominal circle definitions defined by these two schemata is $3 * 3 = 9$. When you are finished, select *"Okay"* (mouse, ENTER, Alt+O) at the bottom of the window. A "9" will now appear next to the *"Nominal geometries"* field in the test viewer.

9

the "Form Error Schemas" window

schemata multiply

You should now be back in the viewer. Next select the *"Form errors"* field. This will call the *"Form Error Schemas"* window. In it you will enter the types of form errors to be attached to the current circles, along with their parameters. Each form error you define will be applied to every single nominal geometry definition. Thus, since we defined 9 circle geometries above, if we define 5 form errors, the ATS will generate $9 * 5 = 45$ data sets. (We're only going to define 2 form errors actually.)

10

"Form Error Schemas" window description

The *"Form Error Schemas"* window is divided into three sections: The upper left section, titled *"Error Schema Lists"*, contains a list of form error lists. The upper right section, titled *"Error Schemas"*, contains the form error schemata contained in the selected list. The bottom part of the window is used to enter parameters for a specific form error schema. (All sections of the window are empty as yet.)

lists of schemata - combines form errors

Let's look more closely at the upper two sections of the window: The upper left section contains form error lists. Each list can contain any number of schemata. The purpose of a list is to allow the combination of more than one form error in a single geometry. For example, if we would create a circle form error list containing a random error and a sinusoidal error, a single circle would be generated with both a random and a sinusoidal error. If, however, we would place the two errors in separate lists, it would result in the generation of two circles (or 2 times the number of nominal geometries you defined), one with a random error and the other with a sinusoidal.

More generally, each list contains a number of schemata. Each multiple form error generated from a list will consist of one instance of each schema contained in the list. Thus, extending our above example, if our random error has two instances, and our sine error has three, the total number of errors in the list will be all the possible combinations of the two form errors and the three (i.e. in how many ways can our list combine one of the randoms with one of the sines). The total will therefore be the <u>product</u> of the number of cases in each schema, or $2 * 3 = 6$. Each list, however, is

separate and so the total number of form errors will be the <u>sum</u> of the form errors in each of the lists.

Before getting started, let's take one last look at what is now being displayed. The *"Error Schema Lists"* section contains the names of all the lists defined. By default there is one list named "<list of errors>". To its right is displayed the number of errors contained in the list. The *"Error Schemas"* section displays the error schema contained in the current list. By default the list contains no errors, thus *"<none>"* is displayed. Note that a 1 is still displayed next to the word <none> (and next to the words "Total cases:" at the bottom of the window). This is because the ATS views no form errors as a case in itself. With no form errors, data sets can still be generated; they will simply be free of form errors.

11   We are finally ready to begin defining form errors. You should now be in the *"Error Schema Lists"* section, with the "<list of errors>" list highlighted. This is merely a name. If you would like to change it, simply type over it the name of your choice.

12   Next use the tab key or the mouse to move to the *"Error Schemas"* section. To insert a new form error, press keypad '+' or double-click the mouse. Note that ENTER does nothing as there is nothing to select (*"<none>"* can't be selected as there are no details to enter for it). Also, the INS key cannot be used to insert an error schema. In this window, this key is reserved for switching from insert to type-over mode when *no INS, DEL* editing an error list name. Likewise, to delete a list or schema, you must press keypad '-' and not the DEL key (which also has editing significance). After choosing *inserting a* to insert an error schema, a list of the possible circle form errors will appear before *"sine" error* you. Select *"sine"*.

13   The bottom of the *"Form Error Schemas"* window now displays the information
entering val-   relevant to a sine error. Refer to figure 3. You can enter ranges of values for the
ues for sine   amplitude, frequency, and phase. (See step 7 above for a more complete discussion
errors   of ranges.) Select F1 at any time for further information on the meaning of these parameters. Enter the frequency initial value of 2, limit value of 3, and # of values = 2. Set the initial amplitude value to 0.1. (We're keeping # of values unchanged at 1 here, so there's no need to set the limit value.) The amplitude is given in global coordinate units (and not as a fraction of the circle's radius). Since we kept the default radius of 1 in step 8, an amplitude of 0.1 should be sufficient to make the sinusoidal error visible. When finished, use the mouse to select "Done" at the lower right corner of the window, or press Alt+D twice. (The first Alt+D tells the ATS you are finished with this section of the window. You will be returned to the *"Error Schemas"* section. The second Alt+D tells the ATS you are done with this entire window.) You will be returned to the viewer.
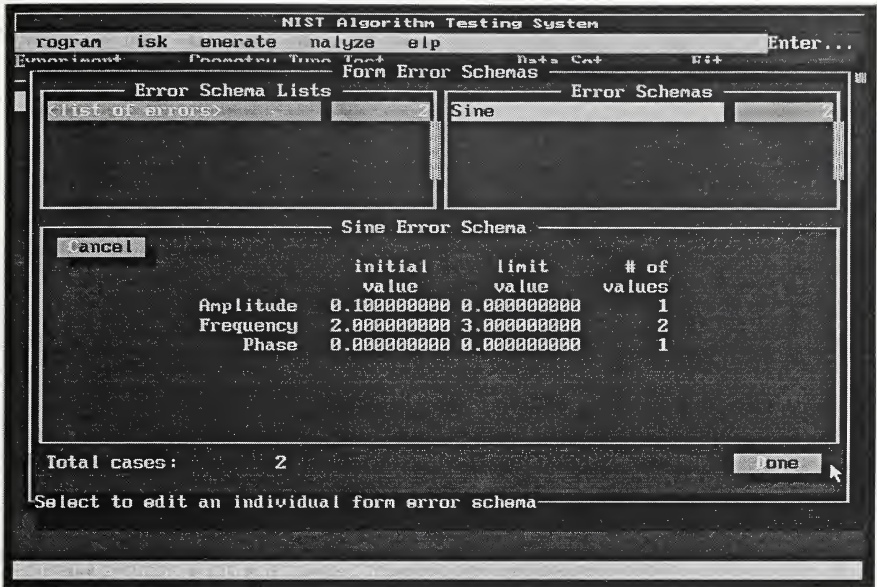
Figure 3 - the *"Form Error Schemas"* Window

14
the "Sampling Plan Schemas" window

Next select the *"Sampling plans"* field in the viewer. This will display the *"Sampling Plan Schemas"* window. You can enable any of the three basic ATS sampling plans - equispaced, stratified, and random. (See explanation in section III, the Overview, or press F1 now for on-line help). Note that by default none of the sampling plans are enabled. (An enabled plan has a check mark next to it.)

15

Enable *"Equispaced"* by pressing SPACEBAR or clicking it with the mouse. Set its start value to 25. Note that each sampling plan is a schema and can be set to a range of values. You can enable more than one at a time (thereby multiplying the total number of data sets). Lastly, the stratified and random plans have a field called *"Replications"*. Since each of them have a random aspect, each replication of the sampling plan will generate different results. Finally, select *"Okay"* (mouse click, ENTER, or Alt+O) to return to the viewer.

16
the "Measurement Error Schemas" window

Lastly, select the *"Measurement errors"* field. We will not introduce any such errors but will quickly view the window. The *"Measurement Error Schemas"* window shows that there are three possible measurement errors - none, uniform, and normal. (See section III, the Overview, or press F1 for more information.) "None" is considered a valid plan; it implies that the data sets of this test should be generated

with no measurement error. Also, as in the sampling plans, you may set the number of replications for the uniform and normal plans. Since each have a random aspect, each replication will introduce a unique error. Return to the viewer.

17   We are at last ready to generate our data sets. First, note the *"Total cases"* field in the viewer. This is the number of data sets our test defines. If you followed the steps above exactly, the number should equal 18 (9 nominal geometries * 2 form errors). Now select the *"Generate"* menu selection (mouse, Alt+G, or F10 + 'g'). Select *"Generate Data Sets..."*. This will call the *"Generate Data Sets from Test"* window.

18   The *"Generate Data Sets from Test"* window contains a number of fields which must be explained. You will find, however, in this window and in general, the ATS *in general* default settings to be adequate. They will allow you to run the ATS under most *keep defaults* circumstances without needing to be concerned with many of its details. We will therefore explain them only briefly. For further details, see the *Reference Manual*, section X.

19   The *"Generate Data Sets"* window contains four fields which you can edit:
the "Generate
Data Sets from   *"Data set name template"*: This field allows you to enter the template which
Test" window   defines how data set names will be generated. The default template is "DS /d/". The "DS" will appear in every generated data set. The "/d/" will expand into an integer corresponding to the sequence number of the data set that is being generated. Thus, "DS /d/" will expand into "DS 1", "DS 2", etc. You can replace the "DS" with any other character string (both before and after the "/d/"). Additional variables are also available besides d.

"Resolution": This field allows you to set the number of decimal places results will be generated to.

"ATS Fitting...": Selecting this field will call the *"Generate Circle Fits"* window. We will not deal with fit generation this lesson. To deselect it, select *"ATS Fitting..."* and turn off all the fitting routines. (The only one selected by default is *"Least Squares"*. To turn it off, SPACEBAR or mouse-click the field so that the check mark disappears.) Select *"Okay"* to exit the window.

"Previously-generated data sets": If you were generating data sets from this test for the second time, the ATS would by default discard all previously-generated data sets. It would assume they were generated from a previous test definition which has now become obsolete (if the test definition had not been redefined, why would you be regenerating it?). You can, however, override this default by setting this field to *"save"*. (Previously-imported data sets, however, are not discarded.)

20

generating data sets status window

Select *"Okay"* at the bottom of the *"Generate Data Sets from Test"* window to start the generation. A status window will appear telling you what is happening. As stated on the bottom line of the status window, you can terminate the generation at any point by pressing ESC.

21

purpose of data set levels

Once the generation is complete, the list of data sets will be displayed in the data set panel. The purpose of the data set level of the hierarchy is to store the list of data sets which are attached to the parent test. In this case, the panel contains data sets which have been generated from the test. Alternatively, you may import data sets and attach them to a test. (We will practice this in a future lesson.)

22

Move over to the data set panel and select one of the data sets. This will cause the data set to be highlighted and will cause the information about it to be displayed in the viewer below.

23

contents of data set viewer

Move down to the viewer (mouse or Alt+PgDn). The right half of the viewer displays the data points. The left half contains a number of fields which display, or link you to displays of information relevant to the data set: You can select the *"Data Set"* or the *"Comments"* field to edit the data set name or comments. There is an additional <u>Instance data</u> section in the viewer. This has four fields - *"Nominal Geometry"*, *"Form Errors"*, *"Sampling Plan"*, and *"Measurement Error"*. Each of these fields calls a window which displays the various parameters applied to the generation of this data set. The parameters reflect a single instance of each of the schemata defined in the test description.

24

viewing data sets graphically

The following two steps apply only to PC's with graphics capabilities. If you have such a PC, you will see a *"Plot data..."* field in the upper right corner of the viewer. Please select this. You will see two new things in the viewer - a graphics window which displays the data set, and a *"View Controls"* panel which allows you to adjust your view. The graphics window contains a wire frame display of the nominal geometry, the generated data points, and the global xyz coordinate system. Closer parts of the geometry are displayed in yellow and farther parts are displayed in dull white. Closer points are drawn larger than farther ones.

view control window

Using the view control window, you may rotate the image, zoom in and out, and pan. You may set the rotation increment by entering a new value in the increment field. You may zoom by using the arrows, or by entering a new value in the zoom value field. The starting zoom position (of 100%) places you at a distance so that the data set fills the graphics window. Figure 4 illustrates a typical view in the graphics window.

25

One additional note on the view control window is appropriate: The view controls

are intended to adjust your own view, rather than the location of the image (which is fixed in space). Thus, if you select to rotate to the right, you are requesting your own orientation to shift to the right. The image will in turn rotate to the left. The same applies for the panning and zooming controls.

26   Examine some of your generated data sets. As above, each was generated from some combination of the nominal geometry and form error schemata we have defined. If you have graphics capabilities, compare your image to the nominal geometry and form error descriptions that may be called from the viewer. When you are done, select *"Program"* and *"Quit"* from the menu (mouse, Alt+P + 'q', F10 + 'p' + 'q'). The ATS will automatically save all of your changes until your next run.
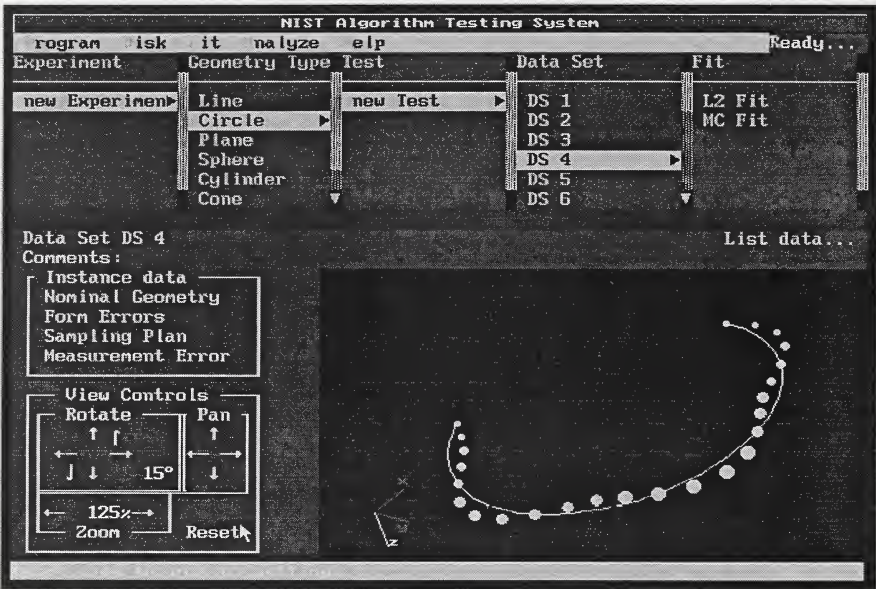

Figure 4 - View of Typical Data Set

Lesson 3 - Exporting and Importing Data Sets

In this lesson, you will learn the I/O and printing capabilities of the ATS.

1   Start the ATS. Nothing is loaded yet. (Again, "loaded" means retrieved from the database to local memory.) The experiment panel displays all of the experiments contained in the ATS. If all you have done until now are lessons 1 and 2, the only experiment you will see is "new Experiment". Press ENTER or use the mouse to select it.

2

once again,
selected vs.
loaded

As we observed in lesson 2 step 2, when you select an object, the ATS reloads all of its previously-loaded descendants. Thus, you should see the ATS load all the way until the data set you were last viewing. (Objects down to the data set level are loaded. Only the current experiment, however, is <u>selected</u> and the current subject of the ATS. The viewer displays additional information about the selected object among the loaded objects.) Move to the first data set ("DS 1") and select it.

3

exporting 1
data set from
the data set
level

operates on
<u>loaded</u> data
set

After loading the data set, use the arrow keys to highlight a different data set, say "DS 3". "DS 1" will be black on gray; "DS 3" will be white on purple. (We request you do this to illustrate a point below.) Move to the menu, and select *"Disk - Export Data Set..."* (mouse, Alt+D + 'e', F10 + 'd' + 'e'). This will call the *"Export data set to file"* window. Before we examine this window closely, note the first line of the window, *"Data set: DS 1"*. Thus, the *"Export Data Set"* command operates on the loaded object ("DS 1") rather than the highlighted one ("DS 3").

4

the "Export
data set to
file" window

ATS creates
legal DOS
name

The *"Export data set to file"* window contains two fields you can edit.

    "File name": The name of the DOS file which will be created. (This may include a drive name and directory names.) By default, the ATS takes the name of the current object, converts it into a legal DOS name (here "DS 1" became "DS1"), and adds a ".ds" suffix. Thus, you should see "DS1.ds" in this field. Normally, you could edit the name to the name of your choice. For the purposes of this lesson, do not edit it.

    "Format": The file format in which the data set will be exported. You can use the mouse or SPACEBAR to toggle between the four possible export formats supported by the ATS. A complete explanation of them may be found in the *Reference Manual*, section XI.A, and in the on-line help. For now, simply accept the default, *"Generic"*. This will add a header line to the file. The header line will contain one piece of information - an integer signifying the number of data points contained in the data set.

Keep the defaults in the export window, and select *"Okay"* (mouse, Alt+O, or tab

there and press ENTER).

Next, we will export all the data sets which belong to the current test. This is done as a test-level command. That is, we will tell the parent test to export all its data sets. Move to the test level panel, and re-select the current test. Then move to the menu and select *"Disk - Export Data Sets..."*. This will call the *"Export Data Sets to File"*

window. This window contains the following two fields you can edit:

> *"File name template"*: This is the template which will be used to generate DOS file names when the data sets are exported. Note that since we are now dealing with exporting multiple data sets, the ATS utilizes a template. In step 4, when the ATS was operating on a single data set, the data set's name was used (possibly with a conversion). The default template, "ds/d/.ds", will generate file names such as "ds1.ds", "ds2.ds", etc. (The "/d/" expands into the sequence number of the data set we are exporting.) For now, keep the default.

> *"Format"*: The file format in which the data sets will be exported. (See the previous step.) For this lesson, keep the default - *"Generic"*.

Select *"Okay"* at the bottom of this window. The ATS will display a status window telling you what it is doing. This window will display the data set which is being exported and the file which is being created.

If you did everything correctly, you will see the *"Duplicate Files Prompt"* warning window (this was supposed to happen). This window is called if you requested to write over a file which already exists. This occurred because we first exported "DS 1" with the name "ds1.ds" from the data set level (step 4), and then we attempted to do the same from the test level (steps 5-6). Use the mouse or SPACEBAR to toggle through your present choices. They are:
> *"Rename File"* - rename the export file to a name you will enter.
> *"Append to Old"* - append this data set to the existing file.
> *"Overwrite Old"* - overwrite the previous contents of the file.
> *"Cancel"* - cancel the export of the current data set (but not the entire process).

Since the two data sets are identical ("DS 1") you can select *"Cancel"*. (You can, however, choose *"Overwrite Old"*. This would overwrite the previous file with the same contents.)

Next, we will re-import a portion of the data sets. Use the arrow keys to move to the data set level. Also using the arrow keys, highlight a data set which is <u>not</u> loaded. (In the next step we will illustrate a feature with this.) Go up to the menu and select *"Disk - Import Data Sets..."* command. The ATS will display the *"Import Data Sets*

from Files" window. It contains four fields which may be edited:

"Data set name template": This is the template which will be used to generate ATS data set names upon import. The default, "DS /d/" would expand into "DS 1", "DS 2" etc. This is the same as the names of the data sets this test already contains. Therefore, change "DS" into "Import".

"File name template": This template will expand into the names of the files the ATS will search for. The default, "ds/d/.ds" will expand into "ds1.ds", "ds2.ds", etc. This is exactly what we want. Keep the default.

"Import count": The number of data sets you want to import. We could set this to 18, the number of data sets which belong to this test (this is the number you exported in steps 5-6). To save time, set this to 5.

"File format": The format in which the files you are importing will be. The default, *"Generic"* is correct. (Data set files may be imported in five formats. For more information on this, see the *Reference Manual*, section XI.A, or the on-line help.)

"ATS Fitting...": This field allows you to generate reference fits for the data sets which will be imported. Selecting this field (mouse or ENTER) will call the *"Generate Circle Fits"* window. Since we are not yet dealing with fit-generation, we will turn off all fit-generation. To do this, select this field. In the fit-generation window disable all fitting routines by toggling off all check marks (see lesson 2, step 19).

9   Finally, select *"Okay"* at the bottom of the window. The ATS will display a status window telling you what files are being imported and what data set objects are being created.

10   Recall that at the start of step 8 we asked you to highlight an unloaded data set. Now,

new data sets imported before highlighted data set   note where the new imported data sets were imported to - before that highlighted data set. Importing looks at the highlighted object, not the loaded one. Also, although the test object is the selected object (and information about it is displayed in the viewer) this command was not done on the test level. If we would have imported data sets from the test level (i.e. if a test object were highlighted), the new data sets would have been placed at the end of the current data set list.

11   Now select some of the data sets you have just imported. As will be described below, (steps 12-14), the viewer displays different information for an imported data set than for a generated data set. Try comparing the imported data sets to the corresponding generated sets. (Compare "Import 1" to "DS 1", "Import 2" to "DS 2" and so on.) (View the data points tabularly or graphically.) The corresponding data sets should be identical.

12 *differences between viewer for generated and imported data sets*	Descend to the viewer (Alt+PgDn, mouse). Now, let's examine the differences between the generated data information and the imported data information. The *"Instance data"* section of the viewer now has two sections instead of four (see lesson 2, step 23). The *"Form Errors"*, *"Sampling Plan"*, and *"Measurement Error"* fields do not appear. These are not used in importing data sets, only in generating them. (We know they came from a test definition, but to the ATS they are just data.)
13 *imported data set geometry definition can be edited* *how imported data sets are attached to geometry definitions*	There is also a difference between the *"Nominal Geometry"* field of the generated data set viewer and that of the imported data set. Please select it. You should now see in front of you an *"Edit Circle"* window. The *"Nominal Geometry"* field of the generated data set calls the *"Circle Data"* window which does not allow editing. The difference is that a generated data set is <u>generated</u> from the nominal geometry description. Thus, the description of the geometry is accurate information. An imported geometry merely became attached to a nominal geometry instance of the test. (The first imported data set becomes attached to the first geometry instance, the second to the second and so on.) But the definition to which it became attached does not necessarily resemble the actual data set. For this reason the *"Edit Circle"* window gives you the option of editing the nominal geometry description. (A more accurate nominal geometry definition may aid various fitting routines.) If you plot the data (on a PC which supports graphics), the graphical display of the geometry wire frame will reflect any modifications you make.
14	The final difference between the generated and imported data viewers is the *"Import Information"* field. Select it to call the *"Data Set Import Information"* window. This window displays information regarding the file from which this data set was imported. Note the second and third fields, *"Time of file at import"* and *"Current time of file"*. These will normally display the same time. If the time stamps differ, the file has been modified since the ATS imported it. Although the ATS uses the original file, this discrepancy may indicate that the ATS is using an out-of-date file.
15 *printing info about the current test* *Ctrl+P*	We are now going to use the ATS's printing capabilities to write into a file the description of much of what we have generated in the last two lessons. Move over to the current test. (It is not necessary to select it again - the arrow keys are sufficient.) An ATS print command may be triggered by moving to the menu (F10, Alt+D, mouse) and selecting *"Disk - Print Test"* or by pressing the hotkey, Ctrl+P. Do either one.
16 *the "Print ATS Object" window*	You should now see before you the *"Print ATS Object"* window. This window allows you to print information regarding not only the current test, but the entire ATS hierarchy as it relates to the test. You can print a description of the ancestors the current test is descended from (one ATS object per level), and of all its descendants (many per level).

This same window is called when you request to print any object in the ATS hierarchy. The subject of this print is the object which was highlighted when you selected the print command (here a test object). Its type is displayed in the upper left corner of the print window and a ">>" is displayed next to it. By default, only the names of its ancestors are printed, whereas most of the information about it and its descendants will be printed.

Most of the fields of this window are "check-fields". They can be toggled on and off using the mouse or SPACEBAR. The top of the window contains the *"destination"* and *"file name"* fields. *"destination"* can be set to *"file"* (the default) or to virtually any other device hooked to your PC. If it is set to *"file"*, you must enter a string as the *"file name"* (or cancel the operation).

You can turn off the print command for a level of the hierarchy by toggling off the *"Print"* field of the corresponding row. This will shade and protect the other fields for that row. The ATS will still print the information about the preceding and succeeding levels in the hierarchy.

Clicking one of the *"More"* fields will call a window which will prompt you regarding the printing of further information specific to that level.

Set the fields of this window according to your preferences and select *"Okay"*.

17

viewing the exported data sets, the test-description file

Exit the ATS (select *"Program - Quit"* from the menu). You should now have a number of files/printouts generated by the ATS. This includes a set of "ds#.ds" files and a test-description file or printout. Examine some of these with the editor or viewer of your choice to ensure their appearance meets your expectations. Note that there is some basic formatting in the test-description file. The ATS inserts margins and does some very simple column aligning. The data set files, and other files generated by ATS export commands, are unformatted.

Lesson 4 - Generating Reference Fits; Performing Analyses

In this lesson you will learn how the ATS generates reference fits and performs analyses. You will also learn how to customize analyses and generate reports of the results.

1

garbage collection

delete operates on high-lighted object

Start the ATS. Select "new Experiment". The ATS should load until the last data set you had selected. Before getting to the details of this lesson we are going to do some garbage collection. In your data set panel, assuming you have completed lesson 3, you should see a list of generated data set ("DS 1", "DS 2", ...) and a list of imported data sets ("Import 1", "Import 2" ...). The imported data sets are duplicates of the generated. (In lesson 3 we had exported the generated data sets and re-imported them.) Thus, there is no reason to keep them. Delete them by highlighting each one, one at a time, and pressing DEL or keypad '-'. (Note that deletion (and insertion) operate on the highlighted data set, even if a different data set is loaded.)

2

fits can be generated while generating/importing parent data sets

Next, we are going to generate reference fits for our data sets. There are actually three methods of doing this. The most efficient, most common method is to generate the fits simultaneously to generating or importing the data sets. Recall that both the *"Generate Data Sets"* window (lesson 2, step 19) and the *"Import Data Sets from Files"* window (lesson 3, step 8) contain an *"ATS Fitting..."* field. This field calls the *"Generate <Geometry> Fits"* window (*"<Geometry>"* is replaced by an actual geometry name, here *"Circle"*) to allow you to generate reference fits at the time of data generation or import. In both previous lessons, we disabled this option (by turning off all the check marks in the fit window) because we were not yet dealing with fit generation. In general, however, this is the recommended fit-generation method.

3

generating fits from the data set or test level

operates on loaded object

To generate fits for already generated/imported data, you have two remaining options. Each of them also call the *"Generate Circle Fits"* window. From the data set level you may select the menu command *"Fit - Compute Fits"*. This will allow you to generate fits for the loaded data set (not necessarily the one the highlighted one). A more powerful command can be called from the test level. Move the to the test panel and select *"Generate - Generate Fits"* from the menu. This command allows you to generate fits for all the data sets belonging to "new Test". (Note again this command operates on the loaded test. However, the test does not have to be selected (or made the focus of the ATS, see lesson 1, step 5), and so it was sufficient to move to the test panel. It was not necessary to re-select "new Test".)

4

You now see before you the *"Generate Circle Fits"* window. Before discussing the specifics of the window, we provide a brief introduction to the three different types of fitting routines which are provided to generate reference fits. As usual, these are discussed in full detail in the *Reference Manual*, section XII.

Least Squares (L2) - orthogonal distance regression (all geometries). This is handled in a special way for circles. First the plane of the circle is found by an L2 fit, and the points are projected onto the fit plane. The circle is then found as a two-dimensional fitting problem.

3-Dimensional Least Squares (L2_3D) - full 3-D orthogonal distance regression (for circles only). This differs from L2 fitting in that the plane of the circle is found simultaneously to the center and radius. The data points are not projected onto the plane (as with L2 fitting); rather, residuals are the 3-dimensional distance from the points to the circle.

Minimum Circumscribed (MC) (or Minimum Radius) - (circles and spheres only) determines the smallest circle (or in three dimensions, sphere) that encloses all the data points. For a circle, the plane of the circle is found with a L2 fit and the points are projected onto the plane, as with L2 fitting.

5

The *"Generate Circle Fits"* window contains the following modifiable fields:

"Fit name template": The template in this field will expand into a fit object name for each fit generated by this command. The "/t/" will expand into a code which corresponds to the type of fitting routine used to generate this fit object. (The codes are the same as the abbreviations introduced in step 4 - "L2" for least squares, "L2_3D" for 3 dimensional least squares, and "MC" for minimum circumscribed.) Thus, for example, when a least squares fit object is generated with the (default) template "/t/ Fit", its name will become "L2 Fit", and so on. These templates allow for much greater customization. Refer to the *Reference Manual*, section X and Appendix B, for details.

"Trust start guess": This field allows you to specify whether the fitting routines should trust the nominal geometry definition as an accurate estimation of the actual geometry. (Some of the fitting routines behave more efficiently if a starting guess can be used.) The default, "Generated data only" is recommended. (Since generated data is generated from the nominal geometry definition, the best fit usually resembles the nominal definition. The nominal definition, however, by default is not trusted for imported data, since an imported data set may not resemble the definition.

"Previous fits": This field allows you to specify whether or not the ATS should save previously generated fits before generating the new ones. It gives you the choices *"save"* (the default), *"discard all"*, and *"discard similar"*. (*"discard all"* implies that all previously generated fits should be discarded. *"discard similar"* implies that only the fits of the same types as the ones which will be regenerated should be discarded. Since we have not yet generated any fits for our data sets,

the setting for this field will have no effect.

"Fit Generation": This section of the window allows you to specify which fitting routines should be used to generate fits. For each routine, you can toggle a fit field on and off (spacebar, mouse), and you can set the *"Iteration limit"*, or the maximum number of times the routine will iterate, and the *"Convergence factor"*, or the value which this routine will consider convergence.

Toggle on the least squares (L2) and minimum radius (MC) routines. Otherwise, keep all window defaults. Select *"Okay"* at the bottom of the window.

6
can only see fit-children of loaded data set

The ATS will display a status window to display its progress. At the end you should only see fits connected to the currently-loaded data set. All of the data sets now have fits attached to them, but only the children of a loaded object are visible. None of the children of the loaded data set are loaded themselves (from the database), but as always, the ATS displays the children of a loaded object, thereby making them selectable.

7
contents of fit viewer

Select any one of the "L2 Fit"s. The viewer now fills with information about the fit. As always, it contains a name (*"Fit"*) and comments fields. It also displays the following information:

The *"ATS fit objective"* and *"Convergence factor"* used in generating this fit.

"Show last analysis..." (shaded in blue): This field is protected and not applicable. Its use will become clear later in this lesson (see step 17).

"Geometry: Fit": The left section of the viewer displays the geometric description of the fitted geometry. (Each geometry is described according to a different set of parameters. The set of parameters per geometry and their interpretation is discussed fully in the *Reference Manual*, section VI.)

"Residual Statistics": The right section of the viewer displays information about the residuals, or the distances between the fitted geometry and the data set points. It displays the min (smallest negative) and max residuals, the sum of their squares, and their standard deviation.

"Plot residuals...": PC's with graphics capabilities contain this field in the upper right corner of the viewer. Selecting this field (mouse, ENTER, SPACEBAR) will cause the viewer to display the fitted geometry graphically. In the next step (if applicable) we will explore the fit using this facility.

8

If your PC supports graphics, select *"Plot residuals..."*. As with the data set viewer

viewing fits graphically	(lesson 2, steps 24-25), you will see two new things in the viewer - a graphics window which displays the fit and a *"View Controls"* panel which allows you to adjust your view. The graphics window displays: a wire frame of the fitted circle; the generated data points; the residuals measuring from the circle to the points; and the global xyz coordinate system. Closer parts of the geometry are displayed in yellow and farther parts are displayed in dull white. Closer points are drawn larger than farther ones. Residuals with positive values are displayed in red; those with negative values in green. Using the view control window, you may rotate the image, zoom in and out, pan, and scale the residuals. (See lesson 2, steps 24-25 for additional information.)

9

scaling the residuals

residuals are scaled already

One new set of controls is also available. These allow you to scale the magnitude of the residuals by powers of 10. (You may either increment or decrement the scaling factor using the arrows, or enter a new value in the power field.) You may have noticed that the residuals had a degree of initial scaling. Generally, the residuals are scaled so that the largest one is approximately 1/10th the size of the entire geometry. This is done simply to make them visible. If the largest residual is less than 1.0e-06 of the geometry, the residuals are drawn at the same scale as the geometry.

10

Now load the corresponding minimum circumscribed fit of the same data set. Note that the MC fit does not have any positive (red) residuals. View a number of fits, both tabularly and graphically. When you are done return to the panels (Alt+PgUp, mouse).

11

performing an analysis

In the next part of this lesson we will perform an analysis. Move to the test level using the arrow keys or the mouse. It is not necessary to select the test. (Although the analysis is performed on the loaded test, it does not have to be selected, see lesson 1, step 5.)

analysis - definition

An analysis compares fit results. You can perform an analysis on the geometry level (for all the fits descended from a geometry), on the test level (all the fits descended from a test), and on the data set level (all the fits attached to a data set). The ATS analyzes a fit of a data set by comparing its geometry to a reference geometry. The reference geometry is the geometric fitting of the data set the ATS considers to be "correct". (Any doubt the ATS has with the correctness of the reference is reflected in the returned uncertainties correlated with the analysis results.) The reference is designated by the user, and would typically be the geometry of one of the ATS-generated fits (known as the reference fit), or the parent data set's nominal geometry definition. The analysis computes various RMS (root mean square) difference values between the reference fits and the other fits. (The difference parameters are the same as many of the parameters used to describe the geometry. See the *Reference Manual*, section XIII, for complete charts.) It also tracks the worst-case fit for each geometric difference. Lastly, it computes corresponding uncertainties for all RMS differences.

12
the "Analysis Control" window

Select the menu command *"Analyze - Analyze Fits"*. This will call the *"Analysis Control"* window. This window contains the following modifiable fields:

"Select Reference Fit Type": This section of the window allows you to select the fit which will be considered the reference. Each analyzed fit will be compared against the corresponding reference fit for its parent data set. (See explanation, previous paragraph.) The reference may be set to the nominal geometry, one of the ATS fits, or to the first fit. We will perform this analysis against the nominal geometry. Keep the default.

"Fit Inclusion": This will call a popup window which will allow you to set the rules for the inclusion of fits based on their "tag" values. We will discuss and illustrate tagging in steps 21-23.

"Print Output": This will call a popup window which will allow you to set specifications for the printing (to file or other device) of further details about the analysis. We will call this window in the next step.

"Print Summary": This will call a popup window which will allow you to set specifications for the printing of the summary of the analysis. (We will generate such a printout in steps 19-20.)

"Result Scale", *"Expanded Uncertainty Multiplier"*: These fields allow you to set scale values for the results, and the multiplier for the expanded uncertainty results. By default "lengths" are scaled by 1000. Often geometric parameters are in millimeters, whereas residual values are best measured in microns.

13
printing analysis output

Select the *"Print Output"* field. This will call the *"Print Analysis Output"* window. This window enables you to print to file, printer, or any device hooked up to your PC information about the analysis. The ATS will print out the geometric differences between each of the fits analyzed and the reference fit. (This is more information than the ATS itself displays. The ATS displays the average and worst-case differences only.) For each fit analyzed the ATS will print a line in the following format:

test index <sep> data set index <sep> fit index <sep> diff1 <sep> diff2 ...

The test index is only printed if the analysis was done on the geometry level (on the fits of multiple tests). The data set index is only printed if the analysis was done on the geometry or test level. "<sep>" refers to a separator (either comma or tab, see below).

You can specify where to print to with the *"destination"* and *"file name"* fields. (See

separator can be comma, can import results into spreadsheet

lesson 3, step 16.) There is also a *"separator"* field, which allows you to specify whether "<sep>" should be a comma or a tab. The tab separator is useful for viewing the output manually. By setting "<sep>" to the appropriate separator, you can import the detailed analysis results into a spreadsheet program or statistical analysis package (many such programs require that values be separated by commas).

14

Enter values to your liking in the *"Print Analysis Output"* window and select "Okay". This will return you to the *"Analysis Control"* window. Select "Okay". The ATS will perform the analysis. At its completion, the viewer will display the analysis results. We will now examine the viewer in detail.

15

contents of the analysis viewer - deviation analysis

The first lines of the analysis viewer display basic information about the analysis, such as the name and type of the object the analysis was performed on (here a test object, "new Test"), the number of fits analyzed, and reference fit type (here "Nominal Geometry"). The bulk of the window, the *"Deviation Analysis"* section, displays the RMS differences between the fits and the references, and the uncertainties associated with each value. A detailed explanation of the parameters compared for each geometry is provided in the *Reference Manual*, section XIII.B. Recall that length values (here the separation and radius differences) were all scaled by 1000.

no plane difference - points were co-planar

The "plane tilts" difference (angle between plane of reference circles and fitted circles) should equal or be very close to 0. This is because the only errors introduced into the data sets of this test were form errors. For a circle, form errors perturb the points within the plane of the circle in the direction of the normal to the circle. Thus, the points of all of our data sets were co-planar. Had we introduced measurement errors in our test definition, errors would have extended in all directions.

16

contents of the analysis viewer - worst case results

Select the *"View worst cases..."* field. This will toggle the *"Deviation Analysis"* section of the window to the *"Worst Case Analysis"* section which displays the worst case result for each difference parameter. The worst-cases display not only displays the worst case difference values and their corresponding uncertainties, but also the name of the fit which returned the result (if there were one).

worst case results - more values than deviation analysis

"Worst Case Analysis" displays two radius values - *"Radius Under"* and *"Radius Over"*, whereas *"Deviation Analysis"* had only a single radius difference. This is because there is only one average radius difference, while there is both a greatest-over and smallest-under worst case radius. In general, difference parameters which can have both positive and negative values (when compared to the reference parameter) will have two worst case values for the greatest positive and smallest negative differences.

17

corresponding fit field - view

The *"Corresponding Fit"* fields allow you to select the fit name (mouse, ENTER). This will load and select the "winning" fit, allowing you to view it in greater detail.

the winning fit Please select any one. This command also places you in the viewer for the fit. The *"Show Last Analysis..."* field is now selectable. This allows you to return to the analysis display in a single step. This can also be done using the menu command *"Analyze - Show Last Analysis"* (but this field allows faster maneuvering). Return to the analysis.

18

analyses are transitory It should be noted that analyses are transitory. An analysis is a reflection of a state of the ATS - it summarizes a comparison of the current set of fits. If you do anything to alter this state, such as generating, importing or deleting fits the analysis will be obsolete. Also, if you select a different ATS object which was not included in the analysis such as a different experiment, the analysis will become unavailable. Thus, when performing an analysis you should take care to fully study or print out its results before making any other modifications to the ATS.

19

printing the analysis summary We will next print out a summary of this analysis. Select the menu command *"Disk - Print Analysis"*. This will call the *"Print Analysis"* window. Recall that the *"Analysis Control"* window contained a *"Print Summary..."* field (step 12). This would have called the same window. (We didn't do it then because we were busy with too many other new features.) It is impossible, however, to request *"Print Output..."* (steps 13-14) any more. "Output" refers to the difference parameters between each fit and its reference. This information is computed during the performance of the analysis and can be printed out simultaneously. At the end of the analysis, however, only the average RMS differences and the worst-case differences are retained. This information is considered the "summary". The ATS both displays it and is capable of printing it so long as the analysis is current.

20

the "Print Analysis" window The *"Print Analysis"* window allows you to specify where to print to and what information about the analysis should be printed. The fields referring to the types of information are for the most part self-explanatory. (We have not yet discussed *"Inclusion Rules"* and will describe and experiment with them in steps 21-24.) *"Comments"* refers to the comments attached to the ATS object the analysis was performed on (here, "new Test"). Enter values to your liking in the window and select "Okay". The ATS will proceed to print out the summary. (You can append this to the analysis output file (step 14) by entering the same file name. When the ATS prompts you with the duplicate files warning (as in lesson 3, step 7) select "append to old".)

21

We will now experiment with tagging. The purpose of tagging is to provide you with more flexibility in the performance of analyses. You may tag individual tests, data sets and fits. You may then exclude objects from an analysis based on their tag values (illustrated below). Tagging (and untagging) is accomplished by highlighting an object (using the mouse or the arrow keys) and selecting the *"Analyze - Tag Object"* menu command, or by pressing '*'. An '*' is displayed next to each tagged

object.

22

tagging - ex-cluding outli-ers

Return to the worst-case view of the current analysis. (Make sure the analysis displays the *"Worst Case Analysis"* section, see step 16.) The analysis window is displaying the names and values of the worst-case fits for each difference parameter. In this step we will tag one of these "worst-case" fits. In the next step we will repeat the analysis excluding the tagged fit. In general, you may want to use this capability to exclude worst-case outliers from an analysis. Select any one of the worst-case fit names. This will load and select the fit. The ATS will fill the viewer with information on the fit and highlight one of the fields in the viewer. Move up to the fit panel. Tag this fit (press '*' or use the menu command).

23

Move back to "new Test" and select *"Analyze - Analyze Fits"*. This will call the *"Analysis Control"* window as in step 12. Keep all the defaults as before, except this time select the *"Fit Inclusion..."* field. This will call the *"Fit Inclusion Rules"* window. This window allows you to set inclusion rules for all the levels included in the analysis (for all the objects at ATS levels below the one at which the analysis is being performed). For each level included in the analysis, (here the data set and fit levels), you can specify whether all fits should be included, tagged ones only, or untagged ones only. Here we want to exclude a tagged fit, so select "Untagged Only" for the fit level. Select "Okay" to return to the *"Analysis Control"* window. Select "Okay" to perform the analysis.

24

When the analysis is complete, you will find a few differences in the analysis window (in the viewer). The number next to "Number of fits" should be one less than before. The average and worst case results should be slightly improved. In particular, the *"Worst Case Analysis"* section will have a different worst-case fit from the one we excluded. In general, one of the benefits of this technique is to exclude fits which appear to be outliers. When you are done viewing the analysis, exit the ATS.

Lesson 5 - I/O of Fits With and Without the ATS Format

In this lesson, you will learn how to perform I/O operations on fits, and you will learn the advantages and disadvantages of using the ATS format.

1

*CMS valida-
tion - the
process*

Suppose you want to use the ATS to test a CMS data analysis software package. In the Overview (section III.B), we summed up the entire validation process in eight steps. It is appropriate to review this process here. Many of the steps involved in carrying out the process have been discussed in previous lessons. The remaining steps may best be explained in the context of the entire process. The following table illustrates the process:

step	action	lesson
1-2	Define and generate data sets according to the types of measurements for which the CMS is used	lesson 2
2	Generate ATS reference fits	lesson 4
3	Export the data sets to floppy disk	lesson 3
4	Read the floppy disk and fit the data sets using the CMS software	N/A
5	Write the fit results to a floppy disk	N/A
6	Re-import the test fits into the ATS	this lesson
7	Compare the CMS fits to ATS reference fits by performing an analysis	lesson 4
8	Generate a report of the analysis results	lesson 4

2

*how do we
import CMS
fits?*

What remains to be explored, therefore, is the importing of fit files into the ATS. (Note: the formatting of fit files is not discussed in the tutorial. It is documented fully in the *Reference Manual*, section XI.B.) There are two methods of importing fits. The first is similar to importing data sets (lesson 3, steps 8-10). The second involves including additional information within the fit file so that it assumes "ATS" format. We will examine both methods and weigh the advantages of each.

3

Start the ATS. Select "new Experiment". This should load objects at every level of the ATS hierarchy, until the fit you had most recently viewed. Select "new Test". Before beginning this lesson, let us examine what is necessary to import a collection of fit files. In a typical scenario, we would be following the eight step procedure delineated above. If we now wanted to compare a CMS's fit results to those of the ATS for all the data sets of "new Test", we would (1) export all the data sets belonging to "new Test", (2) fit the data sets using our CMS, and (3) import the new fits into the ATS. Exporting the data sets is straightforward. At the test level, we would simply select *"Disk - Export Data Sets..."*. This would call a window which would allow us to export all the data sets in a single command. Fitting the data sets is beyond the scope

of this tutorial. This task depends on the software specifications of the CMS. (Details on how to format the information in the fit file is provided in the *Reference Manual*, section XI.B. This will require some manual editing of the output files of the CMS.)

4   Importing the CMS fits is not entirely straightforward. The basic difficulty lies in instructing the ATS to import the fits into the right locations in the ATS hierarchy (i.e. attached to the right data sets). If we wanted to import fits belonging to a single data set, it would not pose a difficulty. We would simply move to the data set level, and select the *"Disk - Import Fits..."* menu command. It would be apparent to the ATS that it should attach the imported fits to the current (loaded) data set. This would not be useful, however, in our situation as described in step 3. We want to import fits to be attached to every data set in "new Test" (one fit per data set). Using the *"Import Fits"* command of the data set level, we would have to import each fit separately.

5   Next move to the test level. Select *"Disk - Import Fits..."* from the menu. This calls the *"Import Fits from Files"* window. This window gives us more of the functionality we want - to import fits to be attached to every data set belonging to the current test. However, as above, there is no obvious way to instruct the ATS which fit belongs to which data set. For example, if your CMS had generated files "fit1.txt", "fit2.txt", ... "fit20.txt", how would the ATS know where to import each fit (i.e. which data set to attach each fit to)?

6
one method -
the fit file
template

One method provided by the ATS to overcome this is the fit file template. The *"File name template"* field of the *"Import Fits from Files"* window contains the template "fit/d/f/.fit". The "/d/" stands for the data set index. The "/f/" stands for the fit index (per data set). Thus, (in the scenario described "ds2.ds" ...) we would want to create fit files named "fit11.fit", "fit21.fit", etc. The first digit corresponds to the parent data set index, and the second to the fit index (always 1 since we are generating one fit per data set). (You could add a dash ('-') between the two numbers for readability. Just add a dash between the "/d/" and "/f/" in the template.) This will require you to manually name the fit files according to the data set indices. You will additionally have to be sure to select the correct test before calling this command. (We are not going to practice this since we do not have any fit files to import.)

7   It should be added that the above method has a shortcoming. There is no *"Import Fits"* menu command at the geometry level. Thus, there is no direct way to import fits to be attached to data sets belonging to multiple tests. We would want such a capability if we were analyzing fits at the geometry level. In such a case, we would want to export all the data sets which belong to a geometry (or, all the data sets which are attached to all the tests of a geometry), fit the data sets, and import the fits. The ATS, however, is not able to deal with I/O from a level higher than the test level.

8
second method - the ATS format

A second method exists for importing fits. It involves including additional information in the first line of the fit file so that it assumes "ATS format". The primary advantage of the ATS format is that the fit itself will contain information describing its location within the ATS. Using this method, it will not be necessary to give fit files specific names in order to allow them to be referenced with a template, as was described in step 6. It will be possible to give the ATS a single command - "import ATS fits", and the fit files themselves will know where they belong. It is also important to note that users of the Algorithm Testing and Evaluation Program for CMS's (ATEP-CMS) service are required to send fits to NIST in ATS format. (A separate set of instructions is available for users of ATEP-CMS.)

required for users of ATEP-CMS

9
ATS format - description

A brief explanation of the ATS format is now provided. The ATS recognizes both data sets files and fits files in ATS format. Besides the general data set/fit information, ATS format files contain the following information:

1)   The first line has the following format:

      ID   <geometry name>   <date>
where,
         ID -   an alphanumeric string which identifies the location of this data set/fit within the ATS hierarchy. (You need not be concerned with the details of this.)
      geometry name - the name of the geometry this object is attached to.
      date - the date of this object's generation, in the form DD-MMM-YYYY.
2)   In data set files, the second line contains an integer corresponding to the number of points in the data set.
3)   Anywhere after the first line, a ';' may appear which signifies that the remainder of the current line contains a comment.

Returning to our scenario, we want our CMS fit files converted into ATS format. How is this done? The following steps illustrate.

10

The first step in generating CMS fits is exporting the data sets. We will export them in ATS format. Firstly, however, if you followed lesson 3, you have already exported these data sets and created files with names "ds1.ds", "ds2.ds" ... (the names the default template generates). To avoid duplicate name collisions, you may either edit the data set file template (by changing the character parts of it), or select menu command *"Program - Go to DOS"* and delete all ".ds" files (type "del *.ds" at the DOS prompt).

11

To export the data sets, be sure you are at the test level (i.e. "new Test" (or the blank line on the test panel) is highlighted). Then select menu command *"Disk - Export Data Sets..."*. This will call the *"Export data sets to file"* window. If you did not

delete the previous data set files in step 9, edit the data set file template slightly. (Do not change the "/d/", only the character parts of it. Be sure the resulting template will expand into valid DOS file names.) The *"Format"* field has default value "Generic". Use the mouse or SPACEBAR to toggle this field until it is set to "ATS". Press "Okay" to begin the export.

12   Recall in step 3 that the CMS tester's next step is to fit the data sets with his CMS software. Since we cannot incorporate this into the tutorial, we will simply export our own fits (and pretend they are CMS generated). To do so, select the menu command *"Disk - Export Fits..."*, which will call the *"Export Fits to File"* window. (Note here that the default template, "fit/d//f/.fit" will expand into the same file names as was expected by the *"Import Fits from Files"* window.) Keep the defaults and press "Okay". We will treat these files as if they were CMS generated.

13   Our next step is to convert the fit files to ATS format. To do this we will have to exit
converting fit   the ATS and edit them. You may exit by selecting *"Program - Go to DOS"*, but the
files into ATS   ATS will still be resident in memory. Sufficient base memory may not remain to
format   invoke the editor of your choice. We therefore recommend exiting the ATS altogether (*"Program - Quit"*).

14   Start an editing session using the editor of your choice. Open file "ds1.ds". Paste the first line onto the clipboard (or equivalent). Open file "fit11.fit" (the first exported fit which had been attached to "DS 1" (as the first "1" implies)). Paste this first line to the start of the file. This is all the information needed to put "fit11.fit" into ATS format. As described in step 8, you may add comments anywhere after the first line by adding a semicolon. Everything on the line of the semicolon beyond the semicolon will be ignored by the ATS. Repeat this process for a number of the data sets and fits you exported. (Paste the first line of "dsx.ds" and copy it as the first line of "fitx1.fit".) For the purpose of this tutorial, you do not need to repeat this for all 18 fits. Three or four should be sufficient. You will, however, need to keep track of exactly how many fits you edited when you import them in step 15.

15   Return to the ATS. Select "new Experiment". Select menu command *"Disk - Import*
importing fits   *ATS Fits..."*. It is not necessary to select "new Test" or move beyond the experiment
in ATS format;   level. The reason is that the fits themselves "know" where they belong in the ATS
can be done   (i.e. the ATS will read the ATS information within the fit files and interpret it into
from experi-   location information). The ATS now displays the *"Import ATS Fits from Files"*
ment level   window. The default *"Fit name template"* is "Fit /f/". The "/f/" will expand into the number fit we are importing. Thus, by default fits will be named "Fit 1", "Fit 2", ... However, since each fit will be imported and attached to a separate data set, this template is not what we want. Instead, replace the "/f/" with "1". Thus each new fit will be named "Fit 1". The default *"File name template"* is "fit/f/.fit". The exported fits we intend to import are named "fit11.fit", "fit21.fit", ... Thus, edit the template to read

"fit/f/1.fit". Finally, the *"Import count"* (number of fits to import) should be set to the number of fits you edited and put in the proper format in step 14. Select "Okay", and the ATS will begin processing.

16   When the ATS has completed the command, you will see a new "Fit 1" at the end of the fit list of each data set of "new Test". These fits are actually the exported and re-imported "L2 Fit"s of each data set. To confirm this, compare one of the new fits to the corresponding "L2 Fit". The fits should be identical.

17   In summary, there are two methods for retrieving multiple fit files, importing fits with a specialized fit file template (steps 5-7), and importing fits of ATS format (steps 8-16). Both methods require some amount of manual effort. The first requires giving the fit files names which conform to template requirements. The second requires editing the fit files to include ATS format information. The second method has one additional significant drawback: The ATS information which describes the location of a fit becomes obsolete if tests or data sets are added or deleted to the current geometry. Thus, it is only useful if you import CMS fit files immediately after exporting ATS data sets and generating the fit files. In short, the first method is possibly more straightforward. The second, however, is a requirement for users of the ATEP-CMS service, as was mentioned above.