Mechanical System Analysis/Design Tool (MSAT) Quick Guide

HauHua Lee, Mark Kolb, and Jack Madelone
GE Corporate Research and Development Center, Schenectady, New York

November 1998
Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized data bases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at (301) 621-0134

- Telephone the NASA Access Help Desk at (301) 621-0390

- Write to: NASA Access Help Desk NASA Center for AeroSpace Information 7121 Standard Drive Hanover, MD 21076
Mechanical System Design/Analysis Tool (MSAT)

Introduction

MSAT is a unique multi-component multi-disciplinary tool that organizes design analysis tasks around object-oriented representations of configuration components, analysis programs and modules, and data transfer links between them (Figure 1). This creative modular architecture enables rapid generation of input stream for trade-off studies of various engine configurations. The data transfer links automatically transport output from one application as relevant input to the next application once the sequence is set up by the user. The computations are managed via constraint propagation - the constraints supplied by the user as part of any optimization module. The software can be used in the preliminary design stage as well as during the detail design of product development process.

This software has been used in HSCT program to optimize the design of Exhaust Nozzle. It has also been used in design of JSF lift and main engines and GE90 engine. It will be integrated with NASA’s Numerical Propulsion System Simulation (NPSS) that is available to the US aeronautics community, as well as used internally at NASA for coupling conceptual and preliminary design codes for propulsion and propulsion/airframe system analysis. MSAT may be used for design and analysis of any mechanical design where a number of applications from different disciplines are used in simulating a component or a system with multi-component assembly. MSAT has also been integrated with modules such as Monte Carlo, Design of Experiments, Response Surfaces, Optimization to provide robust design and uncertainty analysis capability in preliminary design. This added capability in MSAT identifies whether the product is under-designed (there is a risk) or over-designed (it costs more than necessary).

MSAT software provides global perspective on system design. The plug-and-play framework enables the user to add new applications and/or components and perform quick trade-off studies. This inherent capability is key to “quality” design since 80% of the cost of the product gets locked-in during the initial 20% effort. In addition, MSAT fulfills the critical requirement of providing zooming capability required in NPSS environment. A user can conveniently move from 1-D to 2-D to 3-D using the same user-interface and same tool-set.

Because MSAT framework allows easy extension by adding new modules it can be continuously improved to become more versatile by plugging in new optimization and robust design modules without extensive effort. As new advanced software are developed, a user can quickly plug these in the MSAT environment without throwing away the old pieces. This building-block approach will provide tremendous cost benefits to the developers and designers alike.
The following MSAT Quick Guide provides a condensed description of the MSAT capability. The purpose of this manual is to enable new MSAT users to become familiar with the tool and to begin creating MSAT models with minimal time and effort. A complete and detailed MSAT User's Guide is available on request.

Chuck Lawrence
NASA Lewis Research Center
Figure 1: The Architecture of MSAT Software
Figure 2: Icon-Based Library Browser for Creating Design Models
Mechanical System Analysis/Design Tool (MSAT) Quick Guide

HauHua Lee
Mark Kolb
Jack Madelone
Engineering Mechanics Laboratory
GE Corporate Research & Development Center
Schenectady, NY
Feb. 1998

This quick guide provides a concise description about the use of MSAT system. MSAT is an object-oriented modeling package for representing engineering artifacts in terms of attributes and constraints on those attributes. The physical objects comprising a system are modeled as component objects. System-wide properties (e.g., total weight) are defined using ensemble objects. The analyses applied to these components to determine their properties and performance are modeled as program and module objects. To permit maximum flexibility and modularity, components are not directly associated with their analyses, but instead communicate via intermediate link objects. This makes it easy to add new analyses, and to switch to more sophisticated analyses as the design progresses. Designs are modeled by creating instances of the appropriate component, ensemble, program, module, and link classes. Constraint propagation manages the flow of data among the instances.

This document contains two parts. Part A presents major system features for end users. Part B illustrates an example of application development processes. In Appendix, a general comparison between MSAT and other similar systems is provided.

Part A : Running MSAT

Step 1. Starting MSAT GUI

Figure A.1 shows the MSAT’s top level window, invoked by entering "client" command at UNIX level. Click on "Server -> Start Server" to initiate the MSAT kernel process.

Step 2. Creating MSAT Models

Figure A.2 shows the class library window, which displays entities predefined by application developers. To create a new model from this library, first declare a new model by clicking on "File -> New" on Top-Level window and a model window with empty canvas pops up, then select the entity and click on "instantiate" - the instantiated entities then show up in the model window canvas, as shown in Figure A.3. Note that the graphical connections among entities are established via the instantiation of link entities.
To view the content of a model, first select an entity on the model canvas, then click on "Display", then an entity window pops up, as shown in Figure A.4. At present, only parameters (with values) can be viewed. To find out other detailed information about entities, one needs to refer to the entity files.

**Step 3. Executing MSAT Models**

The execution of MSAT models is invoked by changing parameter value in the entity window and then click on "Submit Changes". The model window does not show the execution sequence explicitly. To find out such sequence information, one should monitor the model window where entities being executed are highlighted.

**Step 4. Load/Save MSAT Models**

You can load an existing model file (*.model) or save the current model to a file for future restoration. The "File" button on the top level window provides the access to these functions.
Figure A.2. Class Library Window
Figure A.3. Model Window
Part B : Developing MSAT Applications

This section uses a simple example to illustrate the MSAT application development processes. The example involves wrapping up a small UNIX code, called piston, as a MSAT Program entity, then coupling with a trivial Module entity (named Demo), using a Link entity (named Piston_Demo).

Problem Descriptions

The piston problem is illustrated in Figure B.1: the hydraulic piston has four design variables, named
X1, X2, X3, and X4, and computes the volume of oil required to lift the load from 0 to 45 degrees, as well as design constraints about force equilibrium, G1 and G2, maximum bending moment, G3, and a minimum piston stroke G4. The reference values of the design variables are X1=84.0, X2=60.0, X3=84.0, and X4=6.0. This problem is used in the book "Numerical Optimization Techniques for Engineering Design" by Vanderplaats, G., 1984, McGraw-Hill.

Figure B.1. Piston Example Problem

Files Descriptions

The example directory contains the following files:

- **piston** - Executable.
- **piston.indata** - Sample input file for the executable.
- **piston.outdata** - Sample output file for the executable.
- **Piston.program** - Defines the program entity, Piston, wrapping up the piston executable.
- **PistonInputs.inputspec** - Input specification of Piston.program.
- **PistonOutputs.outputspec** - Output specification of Piston.program.
At Unix prompt, the piston code can be executed by "piston < piston.indata". The code requires four parameters, defined as X1, X2, X3 and X4. In the input spec of Piston.program, an additional input parameter, Xsum, was created as the summation of X1, X2, X3 and X4. Xsum was created for the purpose of exercising the constraint propagation. Figure B.2, B.3 and B.4 show the contents of the program definition file and its input/output spec files. The full syntax of these files are accessible from the MSAT on-line help.

Program: Piston
RunCommand: "/home/leeh/Frodo-piston/piston < $$FTMPDIR/piston.indata \n> $$FTMPDIR/piston.outdata"
IOSpecs:
  Inputs isA PistonInputs
  Outputs isA PistonOutputs
EndIOSpecs
Attributes:
  Category: RunCommand
  Integer: ExitStatus
  Default: 0
  EndInteger
  EndCategory
EndAttributes
EndProgram

Figure B.2. Piston.program - defining the program entity Piston.
InputSpec: PistonInputs
FilterCommand: "$$FBINDIR/ssub \n    -template /home/leeh/Frodo-piston/inputs.template \n    > $$FTMPDIR/piston.indata"

Attributes:
  Category: FilterCommand
    Integer: ExitStatus
        Default: 0
    EndInteger
  EndCategory
  Numeric: X1
    Dom: 10
  EndNumeric
  Numeric: X2
    Dom: 10
  EndNumeric
  Numeric: X3
    Dom: 10
  EndNumeric
  Numeric: X4
    Dom: 10
  EndNumeric
  Numeric: Xsum
    Dom: 100
  EndNumeric
EndAttributes

Relationships:
  Equality: "Sum of X's"
    Parameters: X1 X2 X3 X4 Xsum :
    Expression:
      { Xsum = X1 + X2 + X3 + X4; }
    Computes: Xsum
    Expression:
      { X4 = Xsum - (X1 + X2 + X3); }
    Computes: X4
  EndEquality
EndRelationships
EndInputSpec

Figure B.3. PistonInputs.inputspec - defining the input spec of Piston entity.
OutputSpec: PistonOutputs
FilterCommand: "awk -f /home/leeh/Frodo-piston/outputs.awk \ < $$TMPDIR/piston.outdata"

Attributes:
  Category: FilterCommand
  Integer: ExitStatus
  Default: 0
  EndInteger
  EndCategory
  Numeric: G1
  Oom: 10
  EndNumeric
  Numeric: G2
  Oom: 10
  EndNumeric
  Numeric: G3
  Oom: 10
  EndNumeric
  Numeric: G4
  Oom: 10
  EndNumeric
  Numeric: Volume
  Oom: 10
  EndNumeric
  EndAttributes
  EndOutputSpec

Figure B.4. PistonOutputs.outputspec - defining the output spec of Piston entity.

The module entity, Demo, contains only two trivial computations, with three parameters defined, A, B, and C. Figure B.5 shows the module definition in MSAT script.

\[
A = 2 \times B \\
C = 3 \times \sqrt{A}
\]

The link entity, Piston_Demo, establishes the data dependency between the Piston program and Demo module. For illustration, a simple dependency is defined as

\[
X1 = A \\
X2 = B
\]

Figure B.6 shows the link definition in MSAT script.
Module: Demo

Attributes:
  Numeric: A
  Dom: 10
  EndNumeric

  Numeric: B
  Dom: 20
  EndNumeric

  Numeric: C
  Dom: 10
  EndNumeric

EndAttributes

Relationships:
  Equality: "First Equality"
  Parameters: A B ;
  Expression: { A = 2 * B ; }
  Computes: A
  EndEquality

  Equality: "Second Equality"
  Parameters: A C ;
  Expression:
    { C = 3*sqrt(A) ; }
  Computes: C
  EndEquality

EndRelationships

EndModule

Figure B.5. Demo.module - defining the module entity Demo.

Link: Piston_Demo

Linkages:
  Program2 isA Piston
  Module3 isA Demo

EndLinkages

Relationships:
  Equality: "X1 Equality"
  Parameters: Program2.Inputs.X1 Module3.A ;
  Expression: { Program2.Inputs.X1 = Module3.A ; }
  Computes: Program2.Inputs.X1
  EndEquality

  Equivalence: "X2 Equivalence"
  EndEquivalence

EndRelationships

EndLink

Figure B.6. Piston_Demo.link - defining the link entity Piston_Demo.

Running Example
To run the example problem, first make sure that the directory that contains the entity definition files is scanned when MSAT starts up. This is done by including a scan command below in the $HOME/.frodorc:

```
scan "/your/directory/name/example/
```

When the library window comes up, the canvas should contains the entities defined in the example directory. Proceed with the Part A descriptions to define the model. E.g., "File -> New" and then instantiate the three entities to the model, then bring up entity window for the input/output spec of Piston entity, and module entity window of Demo. Changing values of X1, X2, X3 and X4 will invoke the execution of the Piston and Demo entities. Figure B.7 shows the sample screen dump of running this application.

Figure B.7. Running the Example Problem
**Mechanical System Analysis/Design Tool (MSAT) Quick Guide**

HauHua Lee, Mark Kolb, and Jack Madelone

Engineering Mechanics Laboratory
GE Corporate Research and Development Center
Schenectady, New York

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

Responsible person, Charles Lawrence, Structures and Acoustics Division, NASA Lewis Research Center, organization code 5900, (216) 433–6048.

MSAT is a unique multi-component multi-disciplinary tool that organizes design analysis tasks around object-oriented representations of configuration components, analysis programs and modules, and data transfer links between them. This creative modular architecture enables rapid generation of input stream for trade-off studies of various engine configurations. The data transfer links automatically transport output from one application as relevant input to the next application once the sequence is set up by the user. The computations are managed via constraint propagation — the constraints supplied by the user as part of any optimization module. The software can be used in the preliminary design stage as well as during the detail design of product development process.