Allocation of DSST in the new implementation of $\text{Astrody}^{\text{Web}}_{\text{Tools}}$

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ABSTRACT

The original development of The Draper Semianalytic Satellite Theory (DSST) was carried out in Fortran 77; both primary implementations of the DSST (in the R&D GTDS Orbit Determination System and as the DSST Standalone Orbit Propagator) were designed to run from a command line interface. DSST has been included as part of an open source project for Space Situational Awareness and space object catalog work. In 2011, the DSST was included on the $\text{Astrody}^{\text{Web}}_{\text{Tools}}$ Web-Site prototype, which provided a friendly web interface for DSST, thus simplifying its use for both expert and non-expert users. This prototype has now evolved into a stable platform based on the Drupal open source content management system, which simplifies the integration of our own application server. In this work we present the integration of DSST in the new web-site, the new facilities provided by this platform to create a research community based on DSST, and comparison tests which will be available in order to provide the user with a better understanding of DSST.

1. INTRODUCTION

The Open Source Software Suite for Space Situational Awareness (SSA) and Space Object Catalog Work was proposed in [1]. This paper addressed two major issues: the problem of adapting legacy SSA software tools to modern computing environments, and the addition of the new analytic functionality to the operational SSA toolbox. It is worth noting that the adaptation of complex scientific applications to modern computing environments may include multiple reengineering processes: (1) non- invasive encapsulation of existing legacy applications, (2) migration of SSA tools to a language platform employing object-oriented and component technologies such as Java and C++, and (3) the creation of Web 2.0 applications for the SSA functions.

The Draper Semi-analytical Satellite Theory (DSST) [2, 3] is the first in a list of applications which has been included as part of this SSA project. There are two versions of this application. The first version of the DSST is an orbit propagator option within the R&D Goddard Trajectory Determination System (GTDS). The second version is the Standalone DSST Orbit Propagator Package. The DSST algorithm is constantly evolving; generally, new developments have taken place in R&D GTDS and then have been exported to the DSST Standalone[1]. In 2011, the Fortran 77 DSST Standalone was included on the $\text{Astrody}^{\text{Web}}_{\text{Tools}}$ Web-Site prototype [4]. This provided a friendly web interface for the DSST, thus simplifying its use for both expert and non-expert users and starting down the road of making the DSST more accessible to the space flight dynamics communities. The $\text{Astrody}^{\text{Web}}_{\text{Tools}}$ Web-Site prototype which is the basis for this initial web DSST capability is described in [5], [6], and [7]. Later in 2011, a new Java implementation of the DSST in the Orbit Extrapolation Kit (OREKIT) open- source space flight dynamics library was undertaken [8, 9]. An overview of the OREKIT library is given in [10].

Both the web application for DSST and the migration of the DSST to a modern, object-oriented, software platform were identified as Open Source Software for Space Situational Awareness (OS4A) 'technology demonstration' tasks in [1].

[1] This remark does not include the developments that have taken place at the Aerospace Corporation in the context of the MEANPROP program [Glenn E. Peterson, *MEANPROP 1.0 Users Guide*, Aerospace Corporation, Aerospace Technical Report ATR-2007(8617)-2, February 2, 1998 ("public release is authorized")].

The $\text{Astrody}^{\text{Web}}_{\text{Tools}}$ project aims to suggest research and learning practices in order to benefit researchers and students who want to use specialized applications through the Internet to solve new problems or learn basic knowledge about these applications. For this purpose, we are creating a web infrastructure at the University of La Rioja based on the Drupal open source content management system [11], initially limited to the area of tools for Astrodynamics and Celestial Mechanics. We note that the web infrastructure can be extended to other applications. This environment allows, on the one hand, hosting different scientific applications with minimum modifications on the original code, developed by diverse research groups, or individually by other researchers, whilst on the other, scientists and students can execute these applications, in real time, by simply using a browser from anywhere in the world. The framework conceals the algorithmic complexity of the applications from the users while viewing the applications in terms of its inputs and outputs. Moreover, the user can access the e-Learning contents of the above applications.

Fig. 1 shows the four current applications available on $\text{Astrody}^{\text{Web}}_{\text{Tools}}$. Besides DSST, the other applications are:

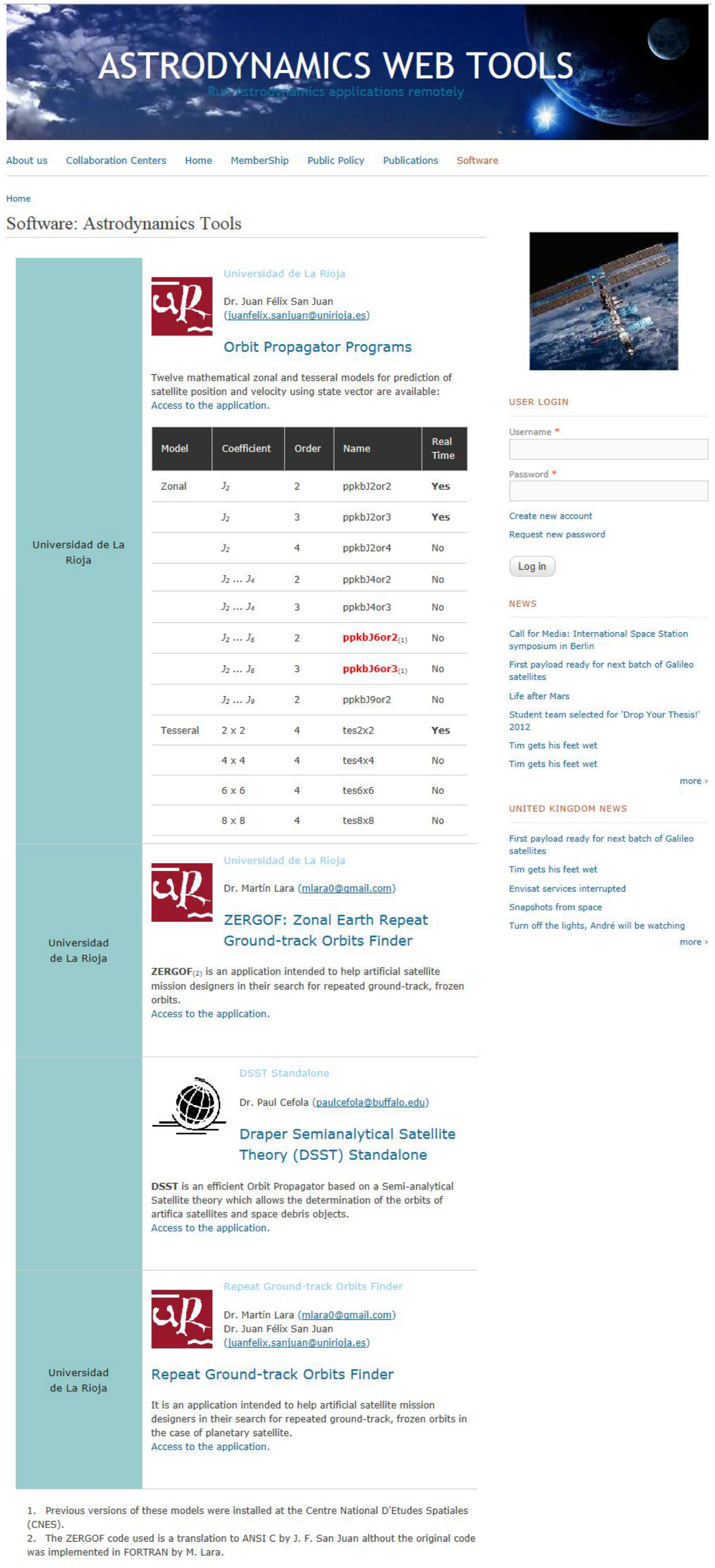
• *Orbit Propagator Program*, is an application, which contains twelve Analytical Orbit Propagator Programs (AOPP). These orbit propagators calculate the orbiter's position and velocity at any given moment directly by means of a function of time and the initial position and velocity of the orbiter.

• *Zonal Earth Repeat Ground-track Orbits Finder* (ZERGOF) is a software package designed to search for repeating ground-track orbits automatically, in the case of the Earth or Earth-like planets.

• *Repeat Ground-track Orbits Finder* is a software package designed to search for repeating ground-track orbits automatically in the case of a planetary satellite.

The DSST was developed by P. Cefola, W. McClain, L. Early, R. Proulx, M. Slutsky, and colleagues, at the Computer Sciences Corporation (CSC) and at the Charles Stark Draper Laboratory (CSDL) in the 1970's and 1980's. In the development at the CSDL, the DSST benefited from numerous enhancements made by Massachusetts Institute of Technology graduate students under the direction of the CSDL staff. The DSST semi-analytical theory employs a nonsingular, mean element strategy that offers significant speed advantages over purely numerical approaches while also offering greatly improved accuracy compared to analytical approaches. Very complete force models have been developed for the mean element equations of motion and for the short periodic motion [12]. This semianalytical theory has been extensively used both for long-term orbit prediction to support mission analyses and to model the orbital motion in orbit determination processes [13]. Currently, the DSST standalone source code is maintained by Z. Folcik and P Cefola. The historical evolution of DSST is discussed in [3].

A brief description of DSST standalone characteristics is given in this paper. Then we describe the integration of DSST into the Web-site and show its use through the Internet. Finally DSST Web is compared with GTDS DSST and DSST Standalone. These tests will provide the user with better understanding of DSST.



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Software: Astrodynamics Tools

Universidad de La Rioja

Universidad de La Rioja

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Orbit Propagator Programs

Twelve mathematical zonal and tesseral models for prediction of satellite position and velocity using state vector are available:
Access to the application.

Model	Coefficient	Order	Name	Real Time
Zonal	J_2	2	ppkbJ2or2	**Yes**
	J_2	3	ppkbJ2or3	**Yes**
	J_2	4	ppkbJ2or4	No
	$J_2 \dots J_4$	2	ppkbJ4or2	No
	$J_2 \dots J_4$	3	ppkbJ4or3	No
	$J_2 \dots J_6$	2	**ppkbJ6or2** (1)	No
	$J_2 \dots J_6$	3	**ppkbJ6or3** (1)	No
	$J_2 \dots J_9$	2	ppkbJ9or2	No
Tesseral	2 x 2	4	tes2x2	**Yes**
	4 x 4	4	tes4x4	No
	6 x 6	4	tes6x6	No
	8 x 8	4	tes8x8	No

Universidad de La Rioja

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Dr. Martín Lara (mlara0@gmail.com)

ZERGOF: Zonal Earth Repeat Ground-track Orbits Finder

ZERGOF (2) is an application intended to help artificial satellite mission designers in their search for repeated ground-track, frozen orbits.
Access to the application.

DSST Standalone

Dr. Paul Cefola (paulcefola@buffalo.edu)

Draper Semianalytical Satellite Theory (DSST) Standalone

DSST is an efficient Orbit Propagator based on a Semi-analytical Satellite theory which allows the determination of the orbits of artifica satellites and space debris objects.
Access to the application.

Universidad de La Rioja

Repeat Ground-track Orbits Finder

Dr. Martín Lara (mlara0@gmail.com)
Dr. Juan Félix San Juan (juanfelix.sanjuan@unirioja.es)

Repeat Ground-track Orbits Finder

It is an application intended to help artificial satellite mission designers in their search for repeated ground-track, frozen orbits in the case of planetary satellite.
Access to the application.

1. Previous versions of these models were installed at the Centre National D'Etudes Spatiales (CNES).
2. The ZERGOF code used is a translation to ANSI C by J. F. San Juan althout the original code was implemented in FORTRAN by M. Lara.

USER LOGIN

Username *

Password *

Create new account

Request new password

Log in

NEWS

Call for Media: International Space Station symposium in Berlin

First payload ready for next batch of Galileo satellites

Life after Mars

Student team selected for 'Drop Your Thesis!' 2012

Tim gets his feet wet

Tim gets his feet wet

more ›

UNITED KINGDOM NEWS

First payload ready for next batch of Galileo satellites

Tim gets his feet wet

Envisat services interrupted

Snapshots from space

Turn off the lights, André will be watching

more ›

Fig. 1: Available applications in $\text{Astrody}^{\text{Web}}_{\text{Tools}}$

2. DSST STANDALONE

DSST Standalone is based on a semianalytical satellite theory expressed in nonsingular equinoctial elements which allows taking advantage of the accuracy of Special Perturbations and the efficiency of General Perturbations, because the influence of the long and short-period perturbations can be decoupled using the Perturbation Theory, and thus handled separately.

The semi-analytical theory replaces the conventional equations of motion with two formulas [3, 14]:

1. Equations of motion for the mean elements

2. Expressions for the short periodic motion

The intent of the semi-analytical theory is that the very small integration grid of the Cowell numerical integration (on the order of hundreds of steps per orbital revolution) be replaced with a much larger step (on the order of one or two steps per day). Such large steps are very computationally efficient. Also, the motion of the non-singular equinoctial mean elements is more linear and this has positive implications for orbit determination processes based on the semi-analytical theory. The semi-analytical theory includes a comprehensive interpolation strategy.

The particular form of the equinoctial elements used in the DSST is described in [15]. This choice is Option (g) in [16].

The force models currently considered in the DSST theory for the mean element equations of motion and for short periodic motion are shown in Tables 1 and 2. We note that Tables 1 and 2 give references for the specific models including the algorithm descriptions and some information about the implementation. Subsequent to the original development, Don Danielson, Beny Neta, and Leo Early provided a summary document for the DSST [35].

Perturbation factors	Mean element equations of motion
Zonal harmonics including C_{20}	Linear terms in general form [17], [18]
Second-degree zonal harmonic	Second-order terms for the a, h, k, p, q, λ rates Terms of order $J_2^2\ e^2$ neglected [19], [20]
Tesseral lm harmonics of geopotential ($2<l<50$, $1<m<50$)	Linear terms, including resonance effects in general form. Modified expansion for the Hansen coefficients [21], [22], [23], [24]
Attraction of the Moon and the Sun	Linear terms in general form [17], [18]
Atmosphere drag	Linear and cross with C_{20} terms. Rates evaluated via quadratures (Harris-Priester, Jacchia-Roberts, MSISE-90) [25], [26]
Solar pressure	Linear terms of direct solar pressure. Rates evaluated via quadratures. Cylindrical model for shadow [25], [26], [27]
Solid Earth Tides	Love number term [28]

Table 1. DSST mean element equation of motion

Perturbation factors	Short periodic motion
Zonal harmonics including C_{20}	First-order terms in a, h, k, p, q, λ treated via a closed-form expansion in true longitude [29], [30]
Second-degree zonal harmonic	Second-order terms in a, h, k, p, q, λ treated via an expansion in true longitude Terms of order $J_2^2\ e^2$ neglected [19], [20]
Tesseral lm harmonics of geopotential (2<l<50, 1<m<50)	Linear terms in general form –partitioned into three categories 1. m-dailies 2. linear-combination terms 3. J_2/tesseral m-daily coupling terms [21], [22], [31]
Attraction of the Moon and the Sun	Linear terms in general form. Closed form expansion in eccentric longitude. Weak time dependent terms [32], [33], [34]
Atmosphere drag	Linear terms via an expansion in mean longitude. Coefficients evaluates via quadratures [26]
Solar pressure	Linear terms via an expansion in mean longitude. Coefficients evaluated via quadratures [26]
Solid Earth Tides	No

Table 2. DSST short periodic motion

DSST is a Fortran 77 based application, which does not incorporate any type of graphical user interface (GUI)[2] during development, thus its execution is made from a command line. This executed mode represents a classical pattern in scientific programming, which we could call a black-box paradigm. The application reads the physical model files, which contain astrodynamics constant data, Solar/Lunar/Planetary ephemerides in either the J2000 or true data coordinates, time conversion coefficients and polar motion coefficients, 50x50 geopotential models, quasi-logarithmic planetary geomagnetic indices and night-time minimum exospheric temperatures for the Jacchia-Roberts atmospheric density model and the user-data files, which contain the initial conditions of the satellite and the configuration parameters of DSST, and the output times are selected by the user. Once data and constants are stored in memory, DSST carries out the calculus and the outputs are stored in two files. Fig. 2 shows the strict Fortran format of the DSST input data file called `pmef.txt`.

[2] In the mid 90's, the Draper laboratory built the Radarsat Flight Dynamics System for the Radarsat 1 SAR mission [36]. This system accessed both the GTDS and the DSST Standalone programs through a User Interface. The Radarsat FDS was implemented on the VAXstation 4000/90 workstation. The system provided a multiprocessing environment through the use of single input/single output modules (executables), with inter-process communication supported by VAX/VMS mailboxes and event flags. This system is being used today as Radarsat 1 is in an extended mission phase. The design of this system was subsequently extended to support the Iridium satellite constellation Orbit Management Requirements but this extension was never implemented in software.

```
C
C
C      PMEF FILE
C
C23456789012345678901234567890123456789012345678901234567890123456789012
   0.2011020700000000D+08 PME_DATE        1
   0.0000000000000000D+08 PME_TIME        2
   0.7204535848109436D+04 ELS_KEP(1)      3
   0.0012400000000000D+00 ELS_KEP(2)      4
   0.9874341600466740D+02 ELS_KEP(3)      5
   0.4332990110790340D+02 ELS_KEP(4)      6
   0.1110000000000000D+03 ELS_KEP(5)      7
   0.6866852509725620D+02 ELS_KEP(6)      8
   0.0000000000000000D+00 ELS_EQUIN(1)    9
   0.0000000000000000D+00 ELS_EQUIN(2)   10
   0.0000000000000000D+00 ELS_EQUIN(3)   11
   0.00000000000000000+00 ELS_EQUIN(4)   12
   0.0000000000000000D+00 ELS_EQUIN(5)   13
   0.0000000000000000D+00 ELS_EQUIN(6)   14
   0.0000000000000000D+00 POSVEL(1)      15
   0.0000000000000000D+00 POSVEL(2)      16
   0.0000000000000000D+00 POSVEL(3)      17
   0.0000000000000000D+00 POSVEL(4)      18
   0.0000000000000000D+00 POSVEL(5)      19
   0.0000000000000000D+00 POSVEL(6)      20
   0.0200000000000000D+01 PME_CD         21
   0.0000000000000000D+01 PME_RHO_ONE    22
   0.5000000000000000D-04 SMA_SIGMA      27
   0.5000000000000000D-04 INC_SIGMA      28
   0.5000000000000000D-04 ASC_SIGMA      29
   0.2100000000000000D+01 PME_SCMASS     30
   0.4000000000000000D+01 PME_SCAREA     31
   0.4500000000000000D+05 PME_STEPSIZE   34
   0.1400000000000000D+02 DP_SPARE1      35
   0.1130000000000000D+03 DP_SPARE2      36
   0.0000000000000000D+00 DP_SPARE3      37
   0.0000000000000000D+00 DP_SPARE4      38
   0.0000000000000000D+00 DP_SPARE5      39
   0.0000000000000000D+00 DP_SPARE6      40
          1               PME_RETRO      41
         11               PME_KEP_SYS    42
         12               POS_VEL_SYS    43
```

```
       1          GEN_METHOD     44
       1          ATMOS_MODEL    45
  840401          JACRB_DATE     46
     123          JACRB_SSS      47
  840401          SLP1950_DATE   48
     456          SLP1950_SSS    49
  840401          SLPTOD_DATE    50
     789          SLPTOD_SSS     51
  840401          TIMECF_DATE    52
     123          TIMECF_SSS     53
       3          HARRIS_MODEL   54
       2          POTNTL_MODEL   55
       2          PME_NMAX       56
       0          PME_MMAX       57
       1          PME_IZONAL     58
       2          PME_IJ2J2      59
       0          PME_NMAXRS     60
       0          PME_MMAXRS     61
       3          PME_ITHIRD     62
       3          PME_INDDRG     63
       3          PME_ISZAK      65
       3          PME_INDSOL     66
       1          PME_JSHPER     67
       1          PME_JZONAL     68
       1          PME_JMDALY     69
       2          PME_INP_TYPE   70
      12          PME_EQUI_SYS   71
      12          INTEG_FRAME    72
      11          OUTPUT_FRAME   73
       0          PME_NSTATE     74
       1          PME_SPSHPER    75
       2          PME_KSPCF      76
       4          PME_INDSET     77
       0          INT_SPARE1     78
       0          INT_SPARE2     79
       0          INT_SPARE3     80
       0          INT_SPARE4     81
       0          INT_SPARE5     82
       0          INT_SPARE6     83
       0          INT_SPARE7     84
       0          INT_SPARE8     85
       0          INT_SPARE9     86
       0          INT_SPARE10    87
```

Fig. 2: `pmef.txt` file.

It is worth noting that the configuration of the user-data file (pmef.txt) is not trivial for a non-expert user; this is in part the case because some options in GTDS DSST are not available in the DSST Standalone version.

3. DSST WEB

Fig. 3 shows the architecture implemented by the   environment. It consists of a Web server, an application server and third-party applications. The Web server has been developed using the content management system (CMS) Drupal, which provides advanced facilities for dealing with security, database connectivity, content management and menu systems. This CMS is written in the Php general purpose scripting language and supported by an active community of users and open source developers around the world. We must note that this environment will be used in the Mechanical Engineering and Bioinformatics fields.

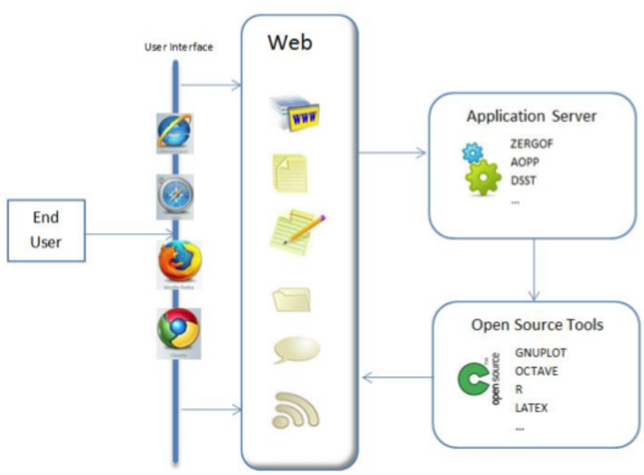


Fig. 3: Astrody$^{Web}_{Tools}$ architecture.

The registered user can select and execute any of the available applications after filling out the appropriate web form. Then, the data included in the form are converted into the input format for the selected application, which is executed by the application server, and the outputs are stored in files. After that, these results can be handled by other open source applications. For example, Gnuplot is the default system used to plot and visualize data, Octave is the interactive system used for doing numerical computations, R is used for statistical calculations, Latex is the word processor, as well as other required applications, and their outputs are embedded in the web page. In addition, the graphics, pdf reports, and other outputs, can be downloaded by the user.

The Astrody$^{\mathrm{Web}}_{\mathrm{Tools}}$ project leaves the DSST Standalone in its current environment and connects it dynamically to our Web framework. The original code remains as its authors programmed it, whereas only its interface has been reengineered. In order to simplify comprehension of the `pmef.txt` file we have introduced an intermediate friendly user-data file such that expert DSST users can use this file to run DSST Web. Fig. 4 shows the new .csv format of the DSST Web user-data file.

```
numVarPmef;NameVar;Value
1; Date; 20120207
2; Time; 000000.0000
3; Reference frame; True of reference (J2000)
4; Kep semimajor axis; 7400.0
5; Kep eccentricity; 0.1
6; Kep inclination; 0.6
7; Kep ascending node; 0.0
8; Kep argument of perigee; 0.0
9; Kep mean anomaly; 0.0
10; Potential models; Grace gravity model GGM01
11; Max degree of central body; 45
12; Max order of central body; 40
13; Max degree of resonance; 43
14; Max order of resonance; 42
15; Atmospheric density model; Harris-Priester
16; F10.7; 100
17; Drag coefficient; 0.2
18; Spacecraft mass; 2.1
19; Spacecraft area; 4.0
20; Iszak J2 height correction; Yes
21; Third body averaging; Off
22; Solar radiation pressure; Yes
23; Solid earth tide indicator; No tidal effects
24; Integration frame; True of reference (J2000)
25; Integration stepsize (secs); 45000.0
26; Integration central body zonal harmonic; Off
27; Integration J22 efect; Off
28; Short-periodic model; 12 Hour high eccentricity Molniya Orbit (moderate accuracy)
29; Output reference; Mean of J2000
```

Fig. 4 New .csv format of the DSST Web user-data file

Fig. 5 shows the encapsulation process followed by the Astrody$^{\mathrm{Web}}_{\mathrm{Tools}}$ team in order to integrate DSST in our software repository.

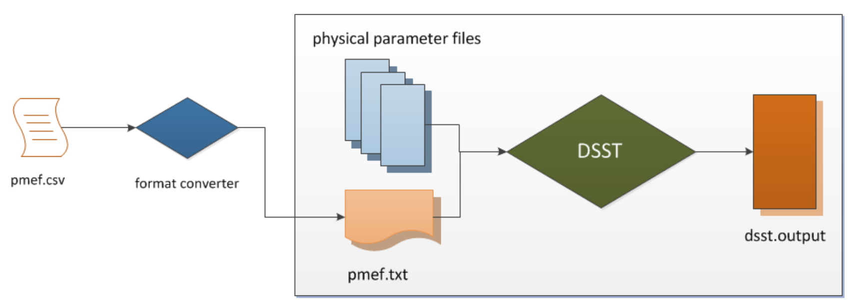


Fig. 5. DSST encapsulation in Astrody$^{\mathrm{Web}}_{\mathrm{Tools}}$ Web-site

The Astrody$^{\mathrm{Web}}_{\mathrm{Tools}}$ Web-site allows registered users to access and execute the original Draper Semianalytical Satellite Theory Standalone through an easy-to-use graphical-user web-interface after completing the appropriate form with the initial values and parameters. This Web interface allows the user to introduce the epoch, epoch mean element set, dynamic parameters, and so on, in two basic ways: the user-data file can be uploaded, or the user can fill in a web form, as Figs. 6, 7 and 8 show. The user-data are converted into the input of the application, which is executed, and the results are stored in files. We must note that DSST Web can simultaneously execute several DSST instances in order to tackle formation flight scenarios or space catalog propagation (Fig. 9). After that, the user-results are processed by other open source applications and their outputs are embedded in the web page. In addition, all the outputs can be downloaded directly by the user.

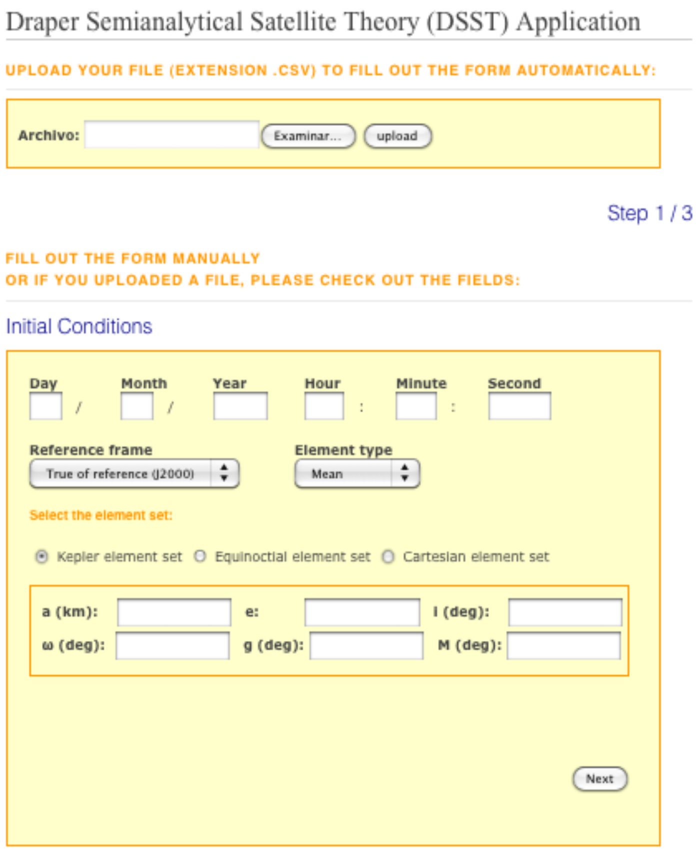
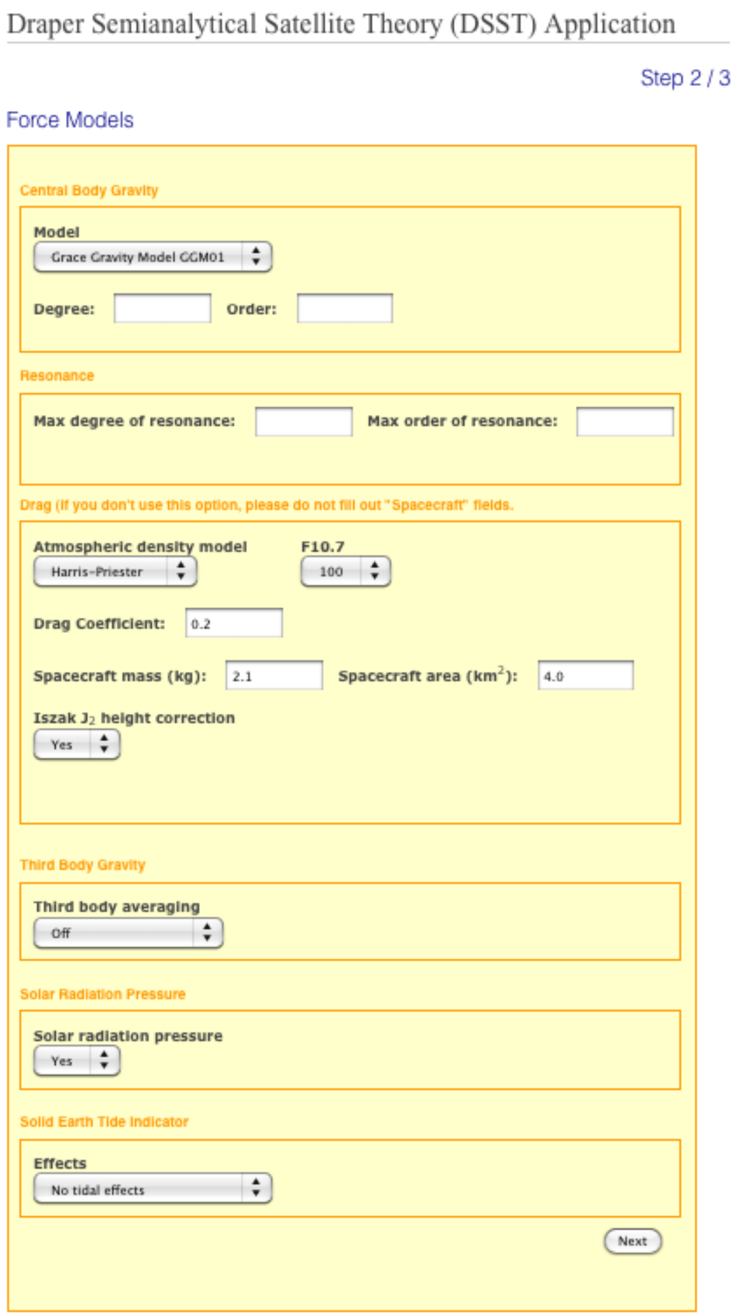


Fig. 6. DSST Web form (Part 1 of 3)



Draper Semianalytical Satellite Theory (DSST) Application

Step 2 / 3

Force Models

Central Body Gravity

Model
Grace Gravity Model GGM01

Degree: Order:

Resonance

Max degree of resonance: Max order of resonance:

Drag (If you don't use this option, please do not fill out "Spacecraft" fields.

Atmospheric density model
Harris-Priester

F10.7
100

Drag Coefficient: 0.2

Spacecraft mass (kg): 2.1 Spacecraft area (km^2): 4.0

Iszak J_2 height correction
Yes

Third Body Gravity

Third body averaging
Off

Solar Radiation Pressure

Solar radiation pressure
Yes

Solid Earth Tide Indicator

Effects
No tidal effects

Next

Fig. 7. DSST Web form (Part 2 of 3)

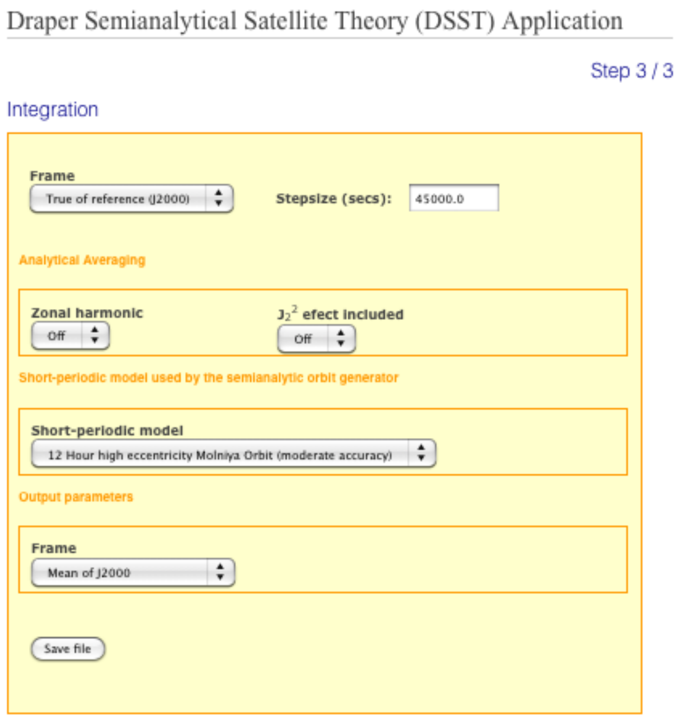


Fig. 8. DSST Web form (Part 3 of 3)

Fig. 9. Execution page

Fig. 10 shows the results provided by the Web-site after the execution of DSST. The information shown is obtained from the two output files generated by this application: dsst.output and SPGOUT. The first contains the Kepler and Equinoctial elements at the output request time. The second is a text file, which stores some of the DSST force model parameters used in its execution and some of its intermediate output: element rate and partial derivative parameters, as well as short-periodic model options and short-periodic Fourier coefficients.

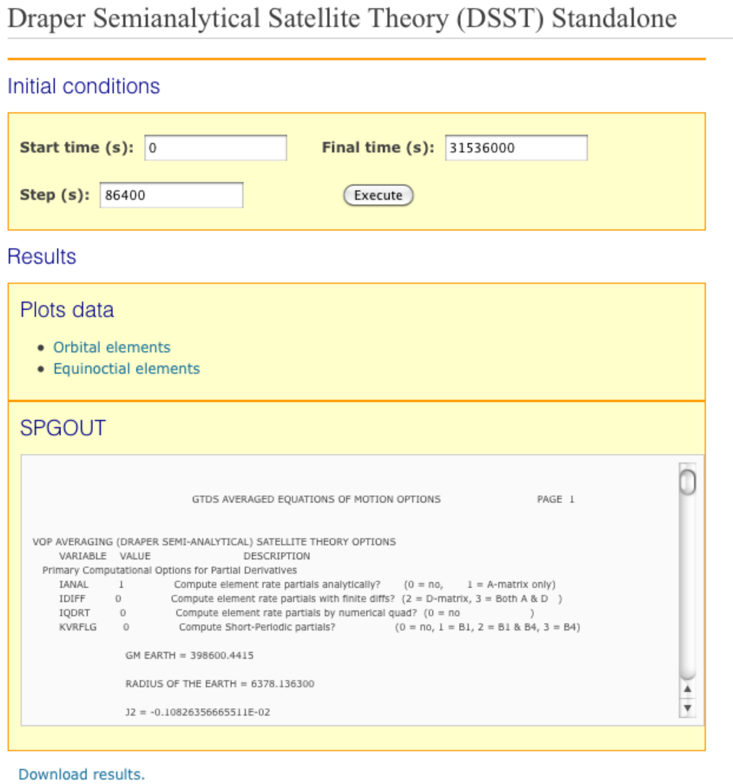


Fig. 10. DSST output Web page

4. TEST CASE

In this section we provide one of a set of test cases, a low inclination Geosynchronous Transfer Orbit (GTO), included in Astrody$^{\text{Web}}_{\text{Tools}}$, in order to illustrate the capabilities of DSST Web. These tests are based on the comparison between the Linux R&D GTDS DSST and GTDS Cowell orbit propagators, where the last will be considered as the true model.

Table 3 shows the assumed Keplerian osculating elements of the GTO orbit.

	Osculating Keplerian Elements
Semi-major axis	27348.233074545 km
Eccentricity	0.523637511301752
Inclination	5.99985975232 deg
RAAN	1.50307478738 deg
Argument of perigee	177.993508218 deg
Mean anomaly	162.105040500 deg
Coordinate system	J2000
Epoch	2011 June 21, 22:03:0.0

Table 3. Keplerian osculating elements

In this case, for the GTDS Cowell orbit propagator, we assumed the following force models:

- GGM02C geopotential model

• 15 x 15 field

• Lunar-solar point masses

• GTDS SLP files for the lunar and solar ephemeris

Before we go further, we note that there are some unique aspects to this test case. First, the period is about 12 ½ hours, so resonance must be considered, but we might not expect the traditional deep resonance. Second, the case must be considered 'high eccentricity.' Third, the test case has a very low inclination, as might occur with a launch site near the equator. Next, the ascending node is nearly aligned with the x-axis in the J2000 frame. Lastly, the perigee is close to the equatorial plane.

Our general plan is to use a Precise Conversion of Elements (PCE) process [37] to create the mean elements at the epoch time.

Our first step was to make a short arc (5 days) DSST run. Here we use the numerical osculating to mean conversion. The results of this step are the truncated DSST models (mean element equations of motion) chosen by the automatic initialization [38]. These are:

• 15 x 0 zonal harmonics

• Tesseral resonant harmonics: (2,2) thru (15,2) [shallow resonance]

• J_2-squared terms

• Lunar-solar point masses

The GTDS Cowell numerical integrator time regularized option [39] was used to propagate the osculating elements over a 75 day span to create the observation data for use in the Precise Conversion of Elements (PCE) process.

The PCE is a least squares fit of one satellite theory to another. There are several factors to be considered:

• The length of the fit span

• The time grid for the observation data

• The assumed errors in the observation data and the data editing parameters

• The 'fit' theory models

• The 'fit' theory partial derivatives

The choice of the 75 day span for the PCE fit was based on previous experience in determining reference mean elements for Molniya orbits [40]. Also 75 days corresponds to exactly 144 orbits (assuming the 12 1⁄2 hour period) of the GTO.

The Cowell integration provided data points at 15 minute intervals, such that there were 50 data points per orbit.

The GTDS DC DCOPT optional parameters and the a priori data uncertainties were set up to inhibit data editing.

The fit theory was the DSST models as chosen by the automatic truncation plus a short periodic model. The averaged equations of motion did include the J2-squared 'closed form' model now under development [41]. The short-periodic models were designed to provide moderate accuracy for Molniya orbits [42]. The fit theory partial derivatives included only the J2 terms [43].

Table 4 shows the Keplerian mean elements coming from the PCE process.

	Mean Keplerian Elements
Semi-major axis	27350.08190032765 km
Eccentricity	0.5236949314607066
Inclination	5.999758529224882 deg
RAAN	1.505656591611563 deg
Argument of perigee	177.9874079699957 deg
Mean anomaly	162.1064920392727 deg
Coordinate system	J2000
Epoch	2011 June 21, 22:03:0.0

Table 4. Keplerian mean elements

A Cowell trajectory was built to use as the true reference for the long GTDS DSST prediction over a 20 year span (using Table 3 initial conditions).

After that we executed the GTDS DSST orbit propagation over a 20 year span using the mean elements fom Table 4 as initial conditions. For GTDS DSST, the same force models were assumed similarly to the GTDS Cowell orbit propagator, but the short-periodic terms are not included.

Figs. 11, 12 and 13 show the time histories and the differences between the two orbit propagators for eccentricity, inclinations and argument of the perigee. We must note that the eccentricity time history indicates that the Cowell and DSST time histories exactly overlap except at a few time points, whereas the inclination and argument of the perigee time histories are even closer to the long period motion.

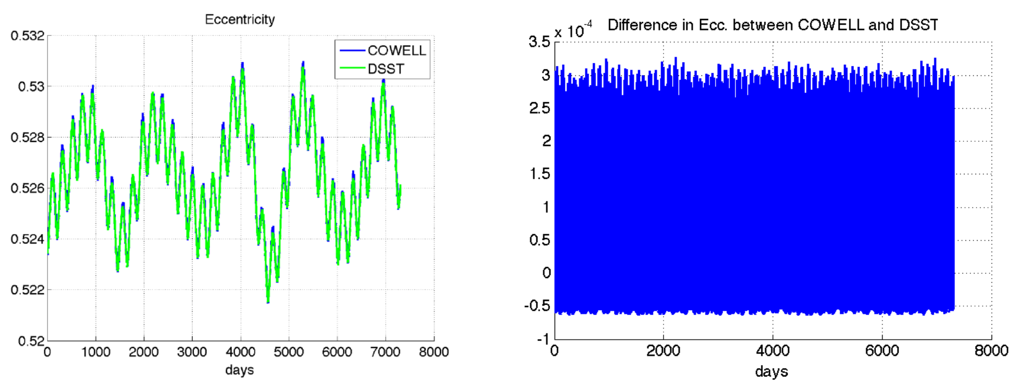


Fig. 11. Time history and difference between GTDS Cowell and GTDS DSST eccentricity

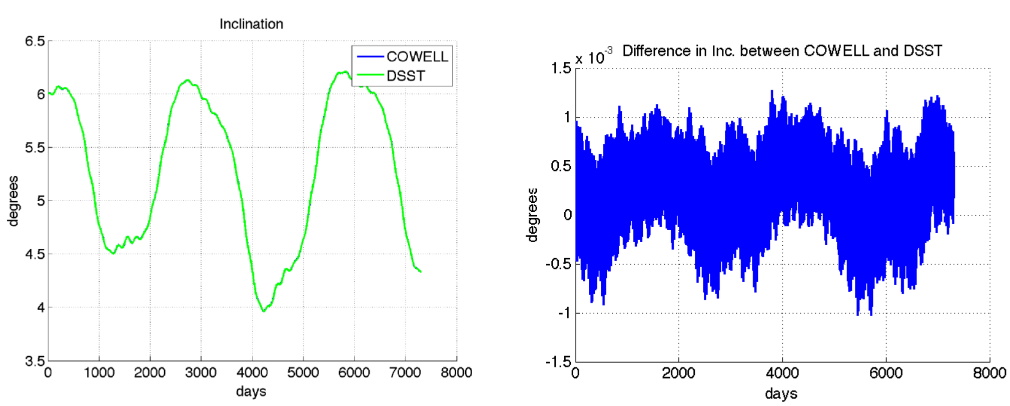


Fig. 12. Time history and difference between GTDS Cowell and GTDS DSST inclination

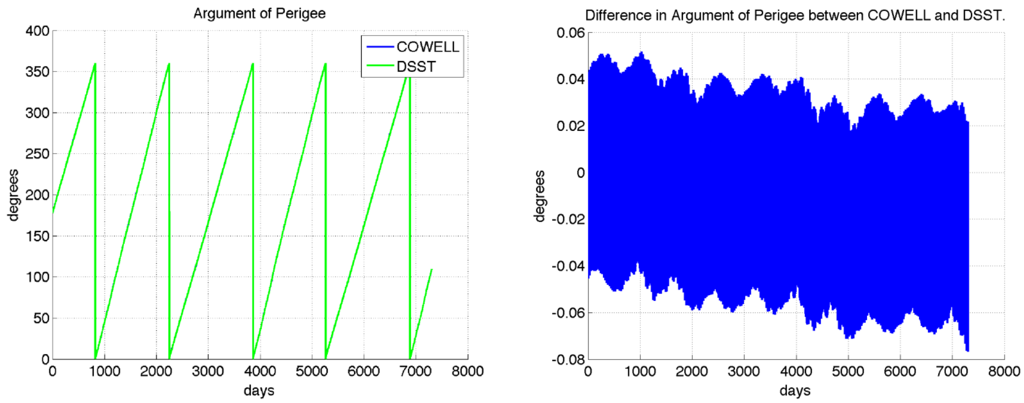


Fig. 13. Time history and difference between GTDS Cowell and GTDS DSST argument of the perigee

Finally we use DSST Web to reproduce the above results. Fig. 14 shows the eccentricity, inclination and argument of the perigee time histories over a 20 year span. As can be seen the plots agree well with the obtained by GTDS DSST. All the files and plots can be downloaded from the Astrody$^{\text{Web}}_{\text{Tools}}$ Web-site.

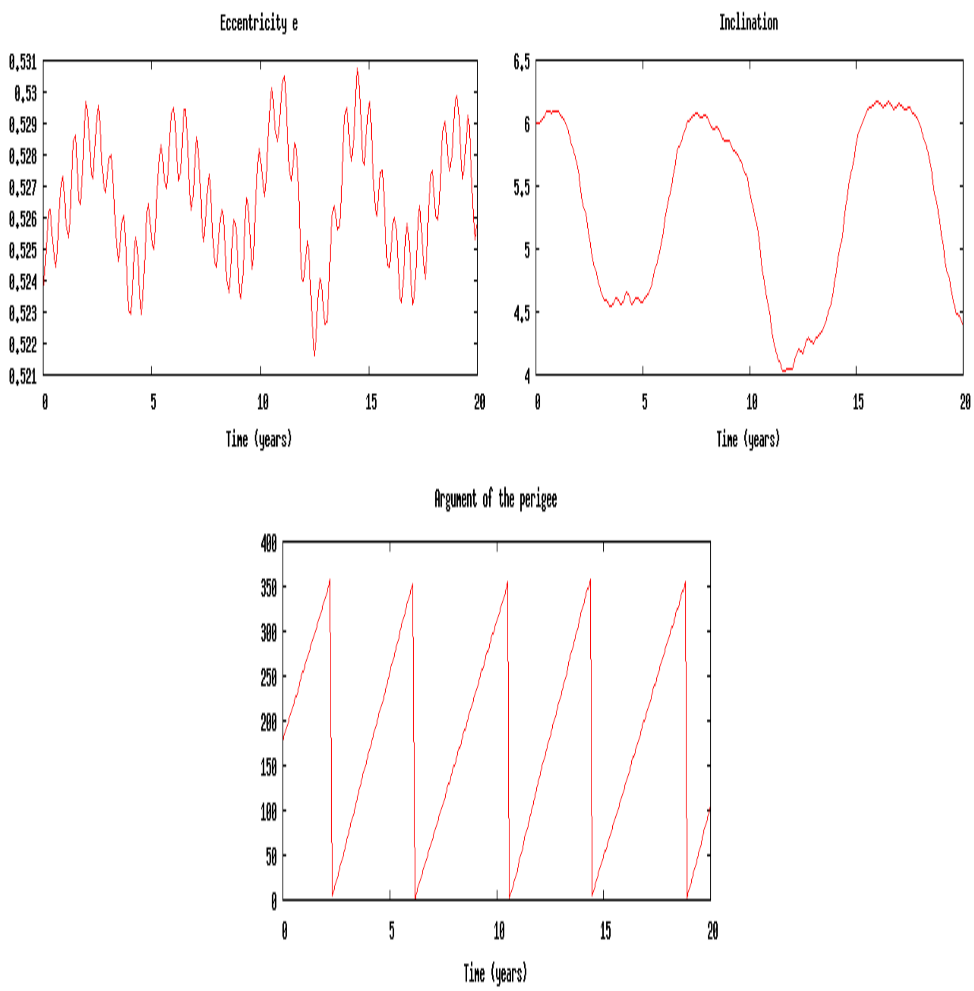


Fig. 14. DSST Web eccentricity, inclination and argument of the perigee time histories

There are some very subtle differences between the GTDS DSST results and the DSST web. For example it considers the inclination history around 1500 days after epoch (Fig. 12 vs. Fig. 13). These small differences may have some connection with the inclusion of the J_2-squared closed form model in the GTDS run and not in DSST Web. The apparent periodic error signature in the Fig. 12 inclination difference and the secular error signature in the Fig. 13 argument of perigee difference both deserve further investigation.

5. CONCLUSIONS AND FUTURE WORK

An initiative for the creation of an Open Source Software Suite for Space Situational Awareness (SSA) and Space Object Catalog Work was proposed at the 4th ICATT [1]. The Draper Semi-analytical Satellite Theory (DSST) is an accurate, efficient and extensively used Semi-Analytical Satellite Theory. This is the first in a list of applications included in this SSA project, which can be used through the $\text{Astrody}^{\text{Web}}_{\text{Tools}}$ Web-site. The inclusion of DSST into our Web framework has been made without any modification to the original DSST code. This paper illustrates the current development of DSST Web and the creation of a repository of comparisons with the Linux R&D GTDS DSST and GTDS Cowell orbit propagators, which will illustrate the capabilities of DSST Web.

The DSST Web allows registered users to access and execute the original Draper Semianalytical Satellite Theory Standalone program through an easy-to-use graphical-user web-interface after completing the appropriate form with the initial values and parameters.

Future work includes the evolution of the DSST Web to a SSA Web application. The SSA Web will necessitate several items:

- A library of orbit determination methods designed to work with the DSST orbit propagator
- Refinements to the current DSST Web capability that facilitate the SSA Web
- A library of observation models
- A database for the raw observation data

Methods for determining the DSST mean equinoctial elements from raw observations are based on weighted least squares (WLS), the Extended Kalman Filter (EKF), the Square Root Information Filter (SRIF), and the Backward Smoothing Extended Kalman Filter (BSEKF). These will form a solid basis for the SSA Web.

Refinement of the DSST web orbit propagator will focus on the functionality required for orbit determination: the interpolators, the short-periodic motion, the partial derivatives, and the coordinate transformations.

The observation models to be considered are radar and optical data. Both ground-based and space-based sensors will be employed.

The SSA web-architecture will be a generalization of the Drupal-based DSST web-architecture given in Fig. 3. Drupal provides a database abstraction layer that supports the management of the observation data.

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