Auxiliary Propulsion System Analysis Tool (APSAT) for Sizing Vehicles

Author: Kris Romig

ABSTRACT

The Auxiliary Propulsion System Analysis Tool (APSAT) was created for use in an integrated design environment to rapidly conduct conceptual vehicle sizing studies. This program primarily sizes orbital maneuvering and reaction control systems but can also be used to size main propulsion for small spacecraft for transfer burns along with attitude control. The vehicle applications include lander vehicles, crew transfer vehicles, RLV OMS/RCS, etc. This model provides the capability to do hundreds of possible combinations of propellant type, tank materials, mixture ratios, etc. using an automated process. The automation of this process helps to decrease analysis time and increase accuracy and fidelity of the various design studies performed.

INTRODUCTION

The Auxiliary Propulsion System Analysis Tool (APSAT) is a propulsion sizing and optimization tool being developed internally within NASA/JSC. The development of this tool has been an ongoing effort for the better part of the last two years and is still in development.
It was determined by propulsion engineers at NASA/JSC that there was a need to have a flexible propellant and propulsion system design tool to perform internal trade studies and support an Integrated Design Environment (IDE). This model was started to aid internal design trades for the on orbit Orbital Maneuvering System/Reaction Control System (OMS/RCS) work that is done at JSC. The intent was to use it within the propulsion group and to support the design of OMS/RCS for future vehicle architectures developed internally at JSC. Outside support of the model has been very encouraging and helpful in the development of the tool for other applications.

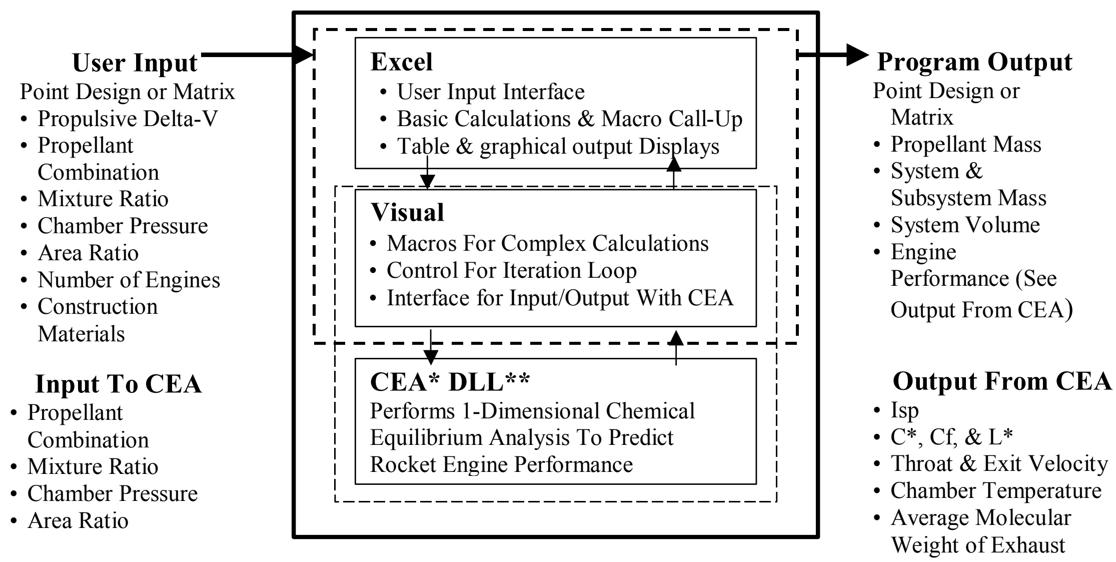
OBJECTIVE

Some of the main objectives in developing APSAT were to provide a capability to generate parametric curves for vehicle mass, volume, and power, while varying propellants, chamber pressure, mixture ratios, materials of construction, etc. This capability was needed to rapidly perform internal trades in the propulsion group at NASA/JSC.

COMPOSITION

APSAT makes use of several different software packages. The primary software used is Microsoft Excel, and Visual Basic. The chemical analysis is performed by a Fortran code that must be linked through a Dynamic Link Library (DLL).

Microsoft Excel is used as a base for the user. This provides a place for the user to make input selections for the system that is to be optimized. The various inputs include propellant combination, mixture ratio, area ratio, chamber pressure, tank/chamber/nozzle materials, number of tanks, pressure fed or pump fed system, delta V, vehicle mass, etc. Some of these inputs are directed through the DLL to the Fortran code, which performs a one dimensional equilibrium combustion analysis. The return output from the Fortran code is then used in Excel as inputs for the sizing model, which then takes the Fortran outputs like, Isp, chamber temperature, characteristic exhaust velocity, etc. and calculates propellant masses, tank volumes and masses, as well as overall system mass, volume and power. The flow of the model is shown in Figure 1



* CEA – Chemical Equilibrium Analysis, FORTRAN code from NASA/GRC

** DLL – Dynamic Link Library

FIGURE 1: APSAT operational flow

Some of the benefits of basing this model in a common Microsoft product are that it makes it portable from one computer to another without the complications of needing to install additional software to run the code. The DLL is capable of running the Fortran code without requiring a separate Fortran compiler software package. The result is that the entire model will fit easily on a single Zip disk or CD-rom and can be easily shared with multiple users.

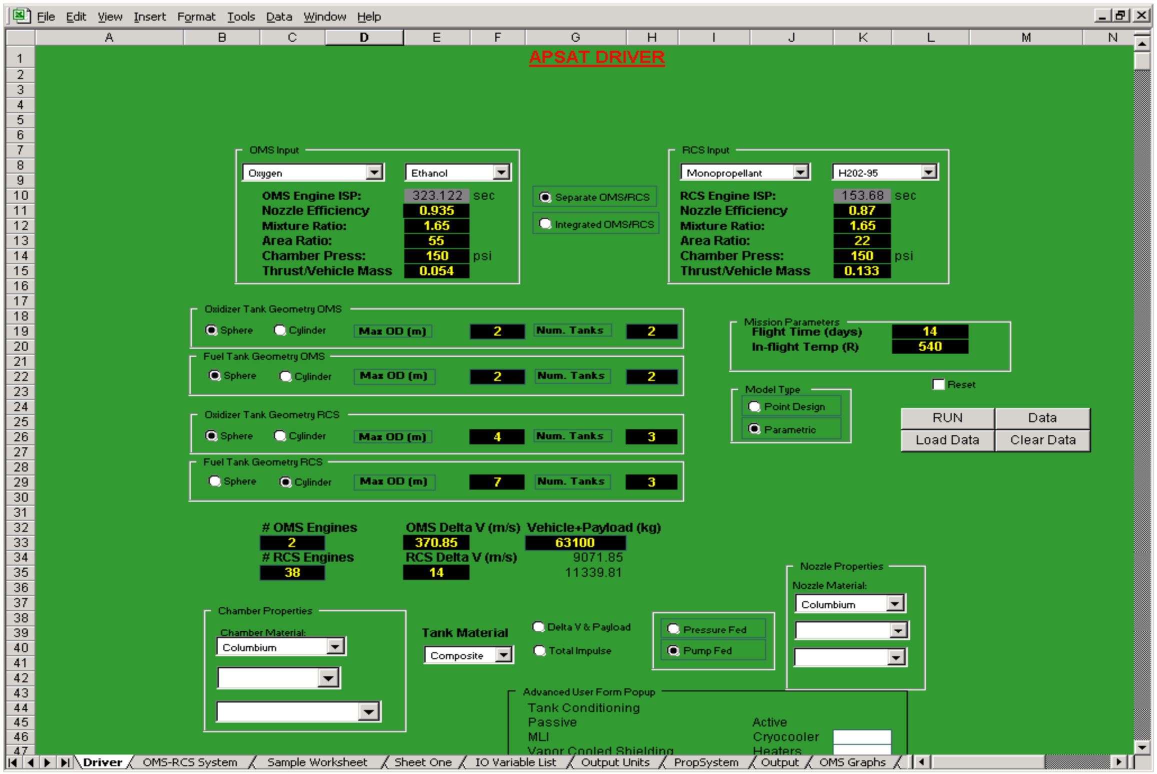


Figure 2: Excel Based User Interface

FUNCTIONS

APSAT is able to perform these sizing and optimization functions in less than a second, which greatly expedites the design/analysis process for new auxiliary propulsion systems. This rapid analysis allows the user to make modifications to the system and ultimately get the optimized concept within a matter of minutes/hours. It also provides hundreds of possible combinations for hardware and reactants alike as well as increasing the accuracy and fidelity to the design process for internal trades.

There are a large number of similar tools that are capable of performing sizing capabilities for propulsion systems. However these models are generally design specific i.e. one model per vehicle or design concept. These tools also often have hardwired data such as Isp and mixture ratio. Modifying these data points often requires the use of another outside tool that will perform the chemical analysis for the desired configuration and then taking that data and inputting it separately into the sizing model. This can make using these tools time consuming and laborious.

This is where APSAT has many advantages. This tool is capable of performing both the sizing optimization and chemical analysis without needing to run separate applications. APSAT is also design specific. It is capable of supporting a multitude of propulsion systems and vehicle/mission requirements. Any modifications needed for a different vehicle or design concept can easily be changed by the user within the graphical user interface (GUI). This makes this tool an all-purpose propulsion system optimization/sizing tool, which is capable of performing analysis in almost any design environment and for many different applications.

UPDATING

APSAT was designed with upgrades in mind. In order to prevent the tool from becoming obsolete shortly after it is finished it needs to be capable of being updated relatively easily. Though internal upgrades will continue as long as APSAT is used, this tool was designed to be updated by the common user not just the author of the model. Not only can materials and new technologies be easily integrated into the Excel sizing tool but new propellant combinations are also easily integrated into the current reactants library with nothing more than a chemical formula and a few physical parameters. The ease with which APSAT can be updated and modified will help to ensure that it remains a valid tool for the design of propulsion concepts in the future.

OUTPUT

There are several ways that APSAT can provide output data because of its Excel base structure. It initially provides data in a table format but it is also capable of autonomous graphical outputs. These graphical outputs are intended to ease the data reduction by the user when common data sets are being evaluated. One example would be the Isp vs. mixture ratio of a particular propellant combination. Since this will be a set of outputs that the designer will be most interested in when optimizing the propulsion system APSAT will automatically create these graphs for quicker referencing. The raw data will always be available to the user at any time as shown below in figure 2. Figure 3 demonstrates the graphical capability of the tool.

	Run #	Propellant	Isp	MR	AR	Chamber Pressure	Total Dry mass	Total Prop Mass	Ox Mass	Fuel mass
	1	o2(l)/methane(l)	343.44	3.8	50	150	1063.42	16961.84	11077.44	2915.11
	2	o2(l)/ethanol	324.13	1.65	50	150	1071.06	17847.86	9264.02	5614.56
	3	o2(l)/ethanol	326.20	1.8	50	150	1066.71	17741.43	9500.19	5277.88
	4	o2(l)/ethanol	326.73	1.8	50	200	1295.73	17715.97	9483.82	5268.79
	5	nto/mmh	314.41	1.65	50	200	1300.18	18402.46	9568.83	5799.29
	6	nto/mmh	315.47	1.65	55	200	1299.85	18361.92	9534.48	5778.47
	7	nto/mmh	315.47	1.65	55	200	1299.85	18361.92	9534.48	5778.47
OMS	8	nto/mmh	315.47	1.65	55	200	688.75	17238.13	7485.01	4536.37
	9	nto/mmh	315.47	1.65	55	200	688.75	17238.13	7485.01	4536.37
	10	nto/mmh	315.47	1.65	55	200	745.19	19001.79	8250.81	5000.49
	11	o2(l)/h2(l)	429.48	6	55	200	1594.54	14964.46	8231.39	1371.90
	12	o2(l)/h2(l)	429.48	6	55	200	1594.54	14964.46	8231.39	1371.90
	13	o2(l)/methane(l)	346.17	3.8	55	200	754.59	16261.53	9517.28	2504.55
	14	o2(l)/methane(l)	343.44	3.8	50	150	664.11	16336.81	9596.46	2525.38
	15	o2(l)/h2(l)	427.31	6	50	150	1292.95	13868.81	8274.72	1379.12

	Run #	Propellant	Isp	MR	AR	Chamber Pressure	Total Dry mass	Total Prop Mass	Ox Mass	Fuel mass
	1	o2(l)/ethanol	284.52	1.65	22	150	84.28	3088.06	1922.75	1165.30
	2	o2(l)/ethanol	284.52	1.65	22	150	84.28	3088.06	1922.75	1165.30
	3	o2(l)/ethanol	285.08	1.8	22	150	84.28	3081.89	1981.22	1100.68
	4	o2(l)/ethanol	285.08	1.8	22	150	84.28	3081.89	1981.22	1100.68
	5	nto/mmh	278.50	1.65	22	150	84.28	3155.71	1964.88	1190.84
	6	nto/mmh	277.18	1.65	20	150	84.28	3170.93	1974.35	1196.58
RCS	7	nto/mmh	277.18	1.65	20	150	84.28	3170.93	1974.35	1196.58
	8	nto/mmh	277.18	1.65	20	150	84.28	5425.43	3378.09	2047.33
	9	nto/mmh	277.18	1.65	20	150	84.28	5425.43	3378.09	2047.33
	10	nto/mmh	277.18	1.65	20	150	91.60	5980.51	3723.71	2256.80
	11	o2(l)/methane(l)	296.85	3.8	20	150	91.60	5575.62	4414.03	1161.59
	12	o2(l)/methane(l)	296.85	3.8	20	150	91.60	5575.62	4414.03	1161.59
	13	o2(l)/h2(l)	373.69	6	20	150	91.60	4409.28	3779.39	629.90
	14	o2(l)/h2(l)	375.85	6	22	150	91.60	4383.57	3757.34	626.22
	15	o2(l)/h2(l)	375.85	6	22	150	91.60	4383.57	3757.34	626.22

Figure 3: APSAT data output

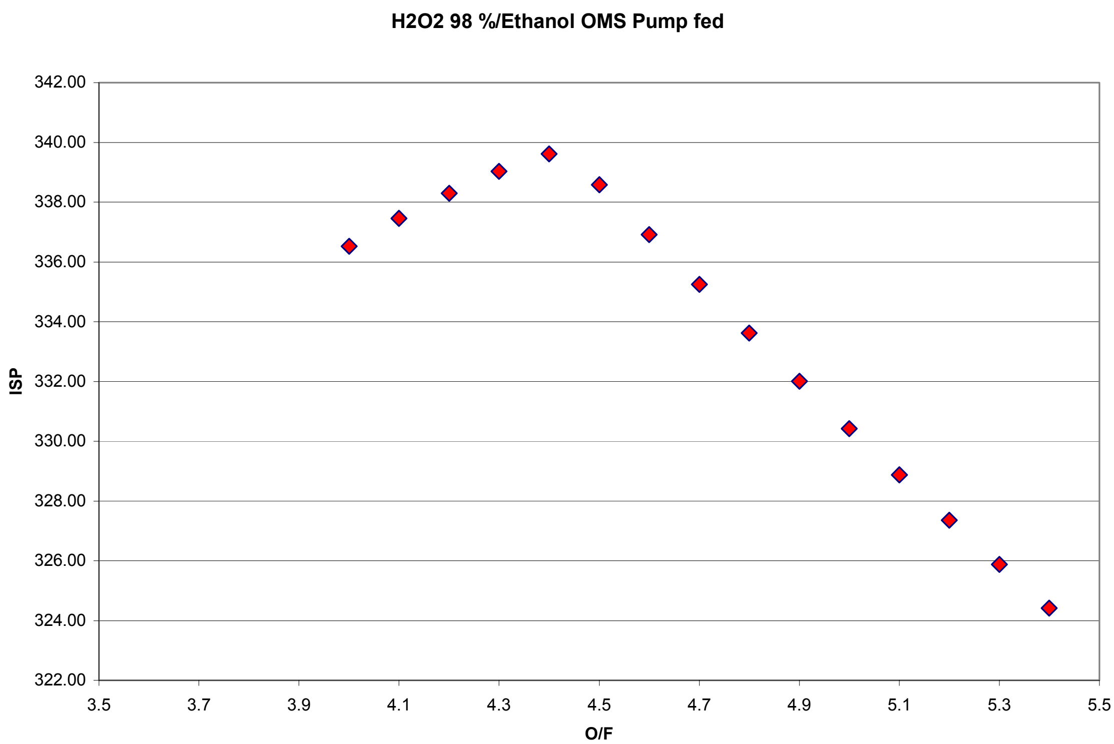


Figure 4: APSAT graphical output

CONCLUSION

APSAT is a propulsion sizing and optimization tool being developed internally within NASA/JSC. This model was started to aid internal design trades for the on orbit Orbital Maneuvering System/Reaction Control System (OMS/RCS) work that is done at JSC. The intent was to use it within the propulsion group and to support the design of OMS/RCS for future vehicle architectures developed internally at JSC. Outside support of the model has been very encouraging and helpful in the development of the tool for other applications.

The model is currently still under development with a great deal of work remaining to be done before it will reach its full capabilities. Many of the models functions have been developed and are currently undergoing testing for accuracy. In order to verify the accuracy, the model's output is being compared with historical data for systems with some flight history such as the current Orbiter's on-orbit propulsion system. APSAT has also been used internally within JSC to assist in the design of several on-orbit propulsion systems for several vehicle concepts such as a Crew Transfer Vehicle (CTV), a Lunar Transfer Vehicle (LTV), and a Lunar Lander.

ACRONYMS

APSAT	Auxiliary Propulsion System Analysis Tool
CTV	Crew Transfer Vehicle
DLL	Dynamic Link Library
GUI	Graphical User Interface
JSC	Lindon B. Johnson Space Center
LTV	Lunar Transfer Vehicle
NASA	National Aeronautics and Space Administration
OMS	Orbital Maneuvering System
RCS	Reaction Control System