System of Systems Model Building and Acausal Simulation Environment

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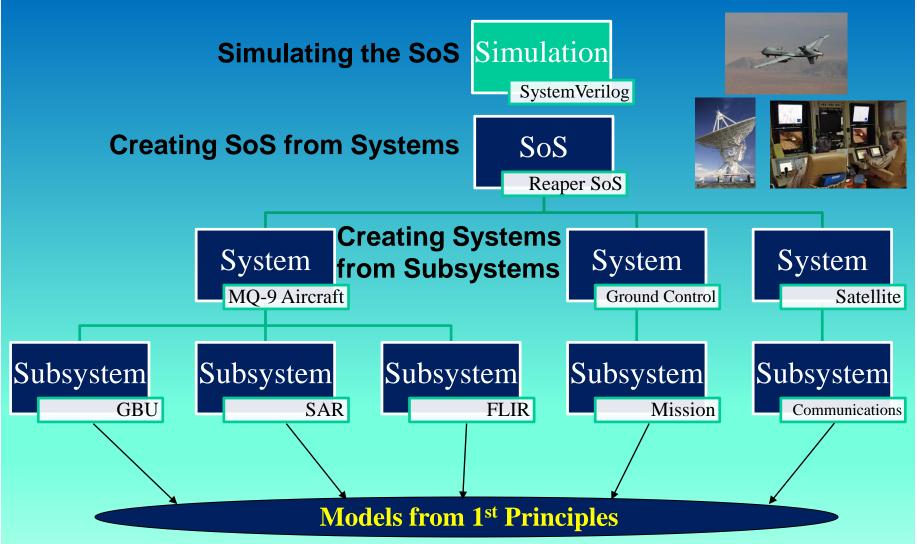
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Technology Motivation

- DoD systems are increasingly complex and challenge human cognitive and organizational abilities. We are now combining those systems into System of Systems.
 - Engineering model flexibility & robustness.
 - Reuse of models.
 - SoS requirements expression and flowdown.
 - Discovering unforeseen behavior through trade studies.
 - Understanding complex results.
 - Accurate simulations, well before we commit.
 - Handling highly scaled simulation problems "digital twin".

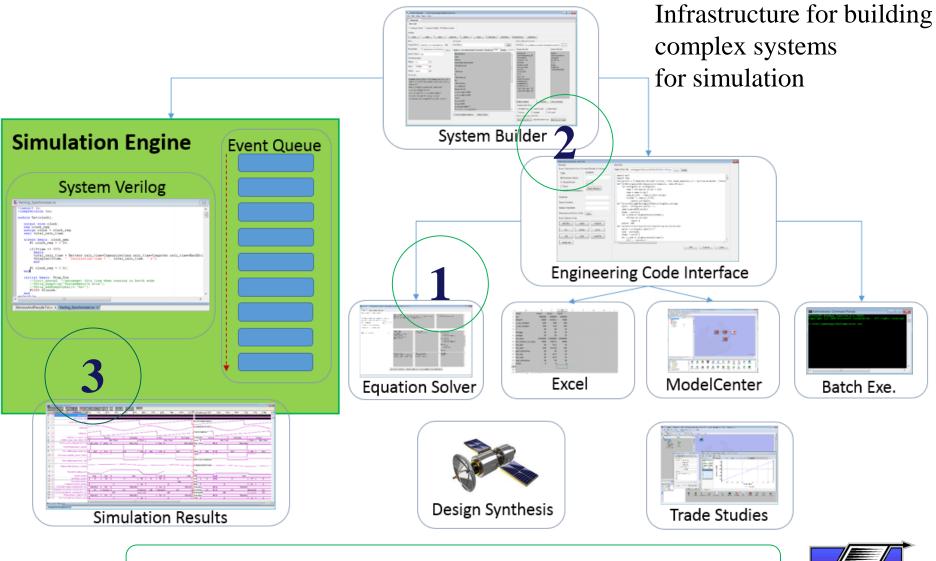


The Basics





System Computation Platform



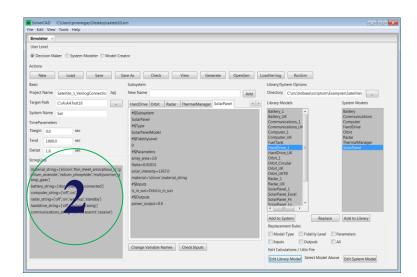
Our approach is to fix weaknesses in the 3 key areas



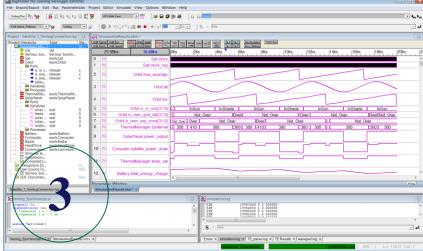
3 Core Elements & Workflow

quation Solver Code Generation Simulation						
Click here to generate a scriptwrapper for this example Click here to generate a function for this example Click here to generate a function Click here to generate a function Lick here to generate af function Lick here to generate af function	#EquationsBegin $rp = zp \cdot Rearth$ $rp = 2 p \cdot Rearth$ $rp = 2^{1}(10 - e)$ $rp = 2^{1}(10 - e)$ $ry that = imu(h)^{1/2}(10 - e) CasiFurctions. Sin/the vither/abart*2 = urbart*2 - r/bart*2 ry the 2/2.0 (-mu/rp) = -1.0^{1}mu(2/2^{16})(va^{4/2}/2.0) (-mu/rp) = -1.0^{1}mu(2/2^{16})$		Solution 1 of 3 = 169450 kilometer writeslater = 3400091379 kilometer/second p = 67780 kilometer write - 2420214804 kilometer/second h = 65747 325979 Kilometer/second writeslater = 342951623228 kilometer/second wrbar = 342951623228 kilometer/second			
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Eqn. Based Model Creator -- Simultaneous equation solver for creating new engineering models for subsystems.



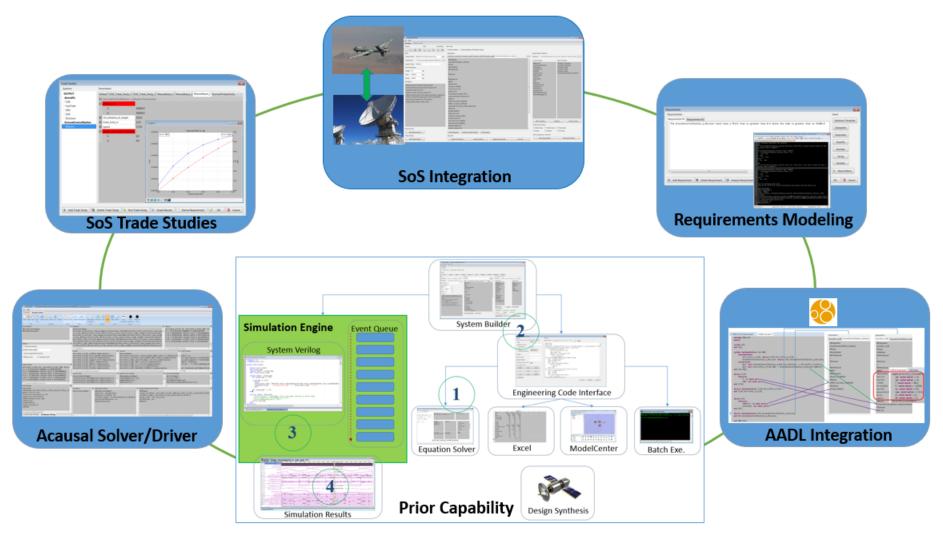
System Builder -- User interface for creating new system models.



System Simulator -- SystemVerilog simulation engine for system model execution and results.



New Capability





Example Problem

PAR base_fuel_consumption_rate=0.045

GroundControlStation x Mission

PAR init_distance_to_target=525.0 PAR target observation distance=6.0

INP SNRsar=Satellite x Comm.SNRsa INP SNRflir=Satellite x Comm.SNRflir INP weight_gbu=Satellite_x_Comm.weight_gbu

INP None OUT fuel_weight=2000.0

PAR altitude_in=40000.0 PAR loiter time in=12.0 DAD cneed-175 @

UT altitude=40000.0 OUT loiter time=13.0 OUT distance_to_target=1000.0 OUT aircraft mode=0.0 OUT start loiter time=200000.0 OUT end loiter time=200000.0 OUT reached target=0.0 UT bombs_dropped=0. OUT Pdetect=0.0 OUT Phit=0.0 OUT Pkill-0.0 OUT Rebot-8 0 OUT ShotDown-0.0

OUT bombs_dropped_out=0.0

An MQ-9 Reaper flies to a target zone and collects sensor data, MULTIANK, MU It identifies a missile site, destroys it and returns to base. The aircraft is equipped with SAR, FLIR, and GBU as part of its system. The ground control station (GCS) controls mission parameters and determines probability of kill. A satellite handles communications between the two.

#####_Aircraft1_x_SAR_#####	
PAR Pt0=320.0	
PAR Daz=44.5	
PAR Dh=16.5	
PAR rhor=1.0	
PAR f=16.7	
PAR fref=16.7	
PAR aw=1.2	
PAR Lsp=2.0	
PAR Lradar=3.16	
PAR Fn=1.33	
PAR alpha=1.0077	
PAR PI=3.14159265	
PAR k=1.380648e-23	
PAR c=299792458.0	
PAR d=0.35	
PAR T=290.0	
PAR etap=0.5	
PAR sigref=3.162e-3	
PAR n=2	
PAR one=1	
PAR Daz0=44.5	
PAR Dh0=16.5	
PAR Le0=51.4	
PAR We0=29.6	
PAR He0=26.7	1
PAR W0=83.0	1
PAR C0=1500200.0	1
INP aircraft_mode_in=Satellite_x_Comm.aircraft_mode	-
INP h=Satellite_x_Comm.altitude	-
INP dtt=Satellite_x_Comm.distance_to_target	-
INP vx=Satellite_x_Comm.speed	-
OUT aircraft_mode=0.0	
OUT SNR=1.00	-
OUT rs=0.0	
DUT R=0.0	
OUT V0=0.0	
OUT V=0.0	
OUT W=0.0	Ρ
OUT Pt=0.0	
DUT C=0.0	

MQ9AG5 tbegin=0.0 tend=82800.0

deltat=3600.0

				OUT KilledTarget=0.0
				###### Aircraft1_x FLIR #####
				PAR 1am1=2.0
				PAR lam2=6.0
				PAR T=500.0
		/	/	PAR PI=3.1415926
	- 1	#####_Satellite_x_Comm_#####	⊐ //	PAR eps=0.95
	- 11	PAR orbit altitude in=117406080.0	1/1	PAR sigma=5.67e-8
		INP aircraft_mode_in=GroundControlStation_x_Mission.aircraft_mode	~ ///	PAR Ac=0.1
	- 11	INP altitude_in=GroundControlStation_x_Mission.altitude	-∡///	PAR Ae0=0.1
	- 11	INP distance_to_target_in=GroundControlStation_x_Mission.distance_to_target	-//	PAR N=1.2e-7
	- 11	INP speed_in=GroundControlStation_x_Mission.speed	-/	PAR AT=20.0
	- 11	INP bombs_dropped_in=GroundControlStation_x_Mission.bombs_dropped	1	PAR vxref=200.0
	-	INP SNRsar_in=Aircraft1_x_SAR.SNR	1	PAR beta=6.7e-5
	(INP SNRflir_in=Aircraft1_x_FLIR.SNR	-	PAR W0=100.0
		INP weight_gbu_in=Aircraft1_x_GBU.weight_initial		PAR P0=280.0
	\	OUT orbit_altitude=117406080.0	X	PAR C0=1000000.0
_mode	•\-	OUT aircraft_mode=0.0		INP aircraft_mode_in=Satellite_x_Comm.aircraft_mode
	•\	OUT altitude=40020.0	₩	INP h=Satellite_x_Comm.altitude
	• \	OUT distance_to_target=6.0	-M	INP dtt=Satellite_x_Comm.distance_to_target
-	•	OUT speed=175.0	-M	INP vx=Satellite_x_Comm.speed
		OUT bombs_dropped=0.0	ΗŊ	OUT aircraft_mode=0.0
-	-11	OUT SNRsar=5.0	11	OUT C=0.0
	- 11	OUT SNRflir=5.0	Y/ //	OUT F=0.0
		OUT weight_gbu=1000.0	K 11	OUT P=0.0
				OUT R=0.0
	/			OUT Rap=0.0
			VIIII	OUT 5=0.0
			11#	OUT SNR=0.0
			LMU .	OUT V0-0.0
			NI	OUT W=0.0
			W	OUT tau=0.0
			V	##### Aircraft1 x GBU #####
			N	PAR weight initial=1000.0
			N	INP aircraft mode in-Satellite x Comm.aircraft mode
			- N	INP h=Satellite x Comm.altitude
				INP dtt=Satellite_x_Comm.distance_to_target
				INP vx=Satellite x Comm.ustance_to_target
				INP bombs_dropped=Satellite_x_Comm.bombs_dropped
			-	OUT weight=0.0
				oor werbuc-ero



	#####_Aircraft1_x_Structure_#####
PAR	base_weight=4900.0
INP	<pre>fuel_weight=Aircraft1_x_FuelTank.fuel_weight</pre>
INP	sar_weight=Aircraft1_x_SAR.W
INP	flir_weight=Aircraft1_x_FLIR.W
INP	gbu_weight=Aircraft1_x_GBU.weight
DUT	total_weight=4900.0



SoS Integration - 1

• First build independent systems: aircraft, ground control station, and satellite. Aircraft is composed of multiple subsystems (e.g. SAR) which can be modeled in equation solver and connected to overall system:

SolverCAD C:\A\PythonWork\solvercad\engine\Example	Problems\SAR.scin			
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New Open Save Save Guess Errors Solve Sort Adjust C	eck Solve Graph Generated Local Time Removi Function Functions Functions Time			
As File Guesses	Solver Misc	Layout Help		
Documentation Equations		Solution		1
2 rs=(dtt*	*etap**2*(Daz*Dh)**2*rhor*(sigref/fref**n)* *2+h**2)**0.5 h/(Daz0*Dh0))**0.5	<pre>i**(n+one)/(8.0*PI*aw*c*k*T*vx*Lsp*Lr 1 Solution 1 2 C = 150000 3 Pt = 320.0 </pre>	.0 USD	
	Dh0)*We0*He0	$4R = 1.0 \dim$		
Settings 5 V=V0*R** 6 W=R**3*W	3 0*LocalFunctions.GetK(R)		3034251815737 dimensionless	
Generate function 7 Pt=R**3*	Pt0*LocalFunctions.GetK(R)		7280000001 centimeter**3	
Function return value: 8 C=C0*R** 9	0.562		0000000014 pound 589634190965 mile +	
Units for generated function Knowns		Guesses E	3 Local Functions	1
Base Units UserInput Units 1 vx=175.0	mile/hour	1 Shirly 110, 120, 13, dimension 1205	1 import math	
Graphics Editor □ 2 dtt=6.0 3 h=40000		2rs,5.0,15.0,1,mile 3R,0.1,10.0,1,dimensionless	<pre>2 def mylog(x): 3 return math.log10(x)</pre>	
h SNR ^ 140000.		4 V0.50000.0.55000.0.1.centimeter**3	4 def mvln(x):	
30000.0 8.9606452188404955 5 Daz=44.5				
40000.0 3.8833034251815737 = 6 Dh=16.5 50000 0 1 6107361330771664 7 rhor=1.6	options m	Utils File		
50000.0 1.6197761239771664 / rhor=1.6 8 f=16.7 g	Insert Calculation from External Model or Library	Open Utils File C:\Users\pmenegay\Desktop\MQ9_Sensor\N	Save	
- 9 fref=16. 10 aw=1.2 c		sigref=passed in object.sigref		Work\AirForce_DUE_Feb8_2017\
11 Lsp=2.0		n=passed_in_object.n		System Models
Graph 1 12 Lradar=	.1 ModelCenter	one=passed_in_object.one Daz0=passed in object.Daz0		Aircraft1_x_Structure
Title	© Excel	Daz0=passed_in_object.Daz0 Dh0=passed_in_object.Dh0		Aircraft1_x_FuelTank
X Label x axis 1 LocalFur X Label x axis 2 LocalFur		Le0=passed_in_object.Le0		Aircraft1_x_SAR Aircraft1_x_FLIR
T Laber y axis		We0-passed_in_object.We0 He0-passed in object.He0		Aircraft1 x GBU
Plot 1	Function	W0-passed_in_object.W0		GroundControlStation_>
Add Graph Add Plot elet 3D	Input Variables	C0=passed_in_object.C0 #call the library function with provided inputs		
Multigraph Settings	Output Variables	r = FunctionLibrary.SAR_3413(vx,dtt,h,Pt0,Daz,Dh,rh	or,f,fref,aw,Lsp,Lradar,Fn,alpha,PI,k,c,	
		<pre>#get the outputs in a convenient numerical form SNR = r['SNR'].magnitude</pre>		
	Generate and Insert Code Go	rs = r['rs'].magnitude		
	Insert Python Code	<pre>R = r['R'].magnitude V0 = r['V0'].magnitude</pre>		
	def (fn.) class import	V = r['V'].magnitude		
		W = r['W'].magnitude Pt = r['Pt'].magnitude		
	for while print	C = r['C'].magnitude		
	list dict read file	return [SNR,rs,R,V0,V,W,Pt,C]	E	
	write file	4		place Add to Library
			OK Cancel Help	delity Level 📃 Parameters
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				File
	Edit Requirements	Generate System Of Systems Generate Ac	ausal System	
		Generate Gene	Edit Library Model	Select Model Above Edit System Model
	Trade Studies	Generate Gene	nate Re-generate	



SoS Integration - 2

• Next, SoS is built by specifying which systems to unite. A flat hierarchy of all contained subsystems results. Variable links must be created.

🍬 SimModelBuilder		
File Help		
Simulator Equation Solver		
Project Files Simulation	User Level	
	Decision Maker System Modeler Model Creator	
Basic	Subsystems	Library/System Options
Project Name MQ9AGS_VerilogConnection.hpj .hpj	Aircraft1_x_SAR Aircraft1_x_FLIR Aircraft1_x_GBU GroundControlStation_x_Mission Satellite_x_Comm <	Directory C:\A\PythonWork\AirForce_DUE_Feb8_2017\Work\Code\1
Target Path C:\Users\pmenegay\Desktop\MQ9_AGS	#\$Subsystem GroundControlStation_x_Mission	Library Models System Models
System Name MQ9AGS	#\$Type	Aircraft1_x_SAR Aircraft1_x_Structure Battery_UK Aircraft1_x_FuelTank
Time Parameters	MissionModel	Communications_UK Aircraft1_x_SAR
Tbegin 0.0 sec	#\$FidelityLevel	Compressor Aircraft1_x_FLIR
sec	1	Computer_UK Aircraft1_x_GBU FuelTank GroundControlStation_x_Mission
Tend 82800.0 sec	#\$VVLevel	HardDrive_UK Satellite_x_Comm
Deltat 3600.0 sec	1	Orbit_Circular
	#\$DeltatLocal	Orbit_UK Orbit_UKTB
StringLists	3600.0	Plant
battery_string=['connected','disconnected']	#\$Parameters	Radar_UK
communications_string=['transmit','receive','off']	altitude_in=40000.0	SolarPanel_Excel SolarPanel_Hi
computer_string=['on','off']	loiter_time_in=12.0	SolarPanel_Lo
harddrive_string=['erasing','saving','off']	speed=175.0	SolarPanel_UK
material_string=['silicon','thin_sheet_amorphous_si','gallium_a	init_distance_to_target=525.0	ThermalManager_MC
rsenide','multijunction_gainp_gaas','indium_phosphide']	target_observation_distance=6.0	ThermalManager_UK
radar_string=['standby','on','off','warmup']	#\$Inputs	
	SNRsar=Satellite_x_Comm.SNRsar:Event	
	SNRflir=Satellite_x_Comm.SNRflirEvent Variable Links	
	weight_gbu=Satellite_x_Comm.weight_gbu:Event #\$Outputs	
	altitude=40000.0:Event	
	loiter_time=13.0:Event	
	distance_to_target=1000.0:Event	
	aircraft mode=0.0:Event	
	start_Joiter_time=200000.0:Event	Add to System Replace Add to Library
	end_loiter_time=200000.0:Event	Add to System Replace Add to Library
	reached_target=0.0:Event	Replacement Rules
Poquiromonto	bombs_dropped=0.0:Event	Model Type Fidelity Level Parameters
Requirements		Inputs Outputs V/V Level
Edit Requirements	Add Subsystem Change Variable Names Check Inputs	
Trade Studies	Generate	Edit Calculations / Utils File
Edit Trade Studies	System Of Systems Acausal System Regenerate Acausal Scin File	Edit Library Model Edit System Model

Simulation Results

• The SoS is simulated using the System Verilog engine and results are shown in a timing diagram:

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1	л		Aircraft1_x_9	Structure.tota	al_weight	7900	9847 96	85 9523	9361 9	199 903	7 8875	8713 8	551 8389	8227 80	065 790	3 7741	7579 7	417 725	5 7093	5931	5769 560	7 5445	=
2	л		Aircraft1_x_	FuelTank.fue	el_weight	3764	<mark>(3602)</mark> 34	40 (3278)	3116 2	954 279	2 2630	2468 2	306 <mark>)</mark> 2144	1982 18	320 165	8 1496	(1334)(1	172 (101	0 848	686	524 362	200	
3	л		A	Aircraft1_x_S				0)				3.8	833034251	18)		0		
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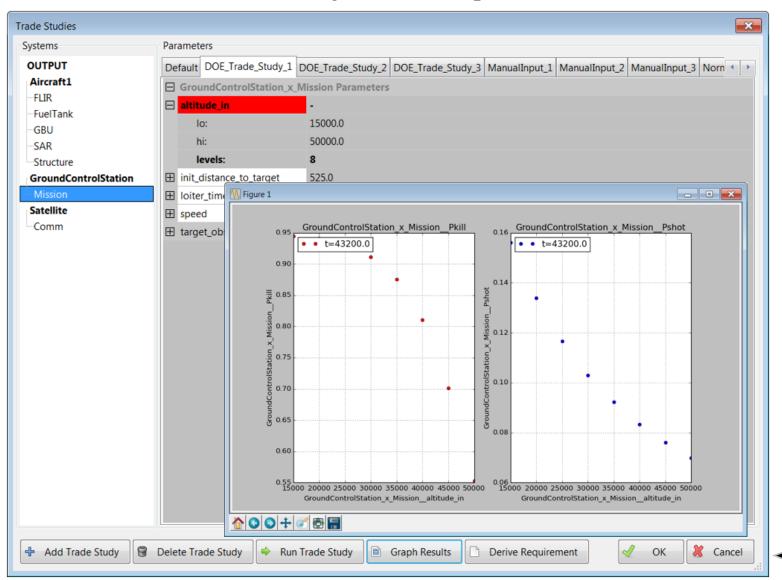
Requirements Modeling

• A template is used to create requirements sentences in English which are translated to Python for analysis. Requirements can also be written directly in Python.

Select Template		Requirement #1: """The GroundControlStation_x_Mission shall have a Pkill that is greater than 0.8 while the time is greater than to 43200.0"""
Select Sentence Template: The <subsystem> shall have a <parameter> that is <equality> <number> The <subsystem> shall have a <parameter> that is <equality> <number> while the <parameter The <subsystem> shall have its <parameter> set to <string> while the <parameter> is <equality> The <subsystem> shall have its <parameter> set to <string> if the <parameter> is <equality> The <subsystem> shall have its <parameter> set to <string> if the <parameter> is <equality> The <subsystem> shall have its <parameter> set to <string> when the time is equal to <number is <pre>inter</pre></number </string></parameter></subsystem></equality></parameter></string></parameter></subsystem></equality></parameter></string></parameter></subsystem></equality></parameter></string></parameter></subsystem></parameter </number></equality></parameter></subsystem></number></equality></parameter></subsystem>	ty> <number> <number></number></number>	<pre>if GroundControlStation_x_Mission_time > 43200.0: if GroundControlStation_x_Mission_Pkill > 0.8: req = True else: req = False else: req = 'W/A' Time #1</pre>
Requirements Requirement #1	OK Cancel	0.0 N/A 3600.0 N/A 7200.0 N/A 18800.0 N/A 18800.0 N/A 18000.8 N/A 25200.0 N/A 25200.0 N/A 32400.0 N/A 18000.0 Study 1 10E_Trade_Study 1
The <subsystem> shall have a <parameter> that is <equality> <number> Select a subsystem Select a subsystem Select a subsystem Full Full Full Full Full Full Full Ful</number></equality></parameter></subsystem>	<pre>> while the <parameter> is <equality> <number> Equality Select One: equal to not equal to OK Cancel Va </number></equality></parameter></pre>	30600.0 M/A Output variables: 42820.0 M/A GoundControlStation_xMission_Pkill,GroundControlStation_xMission_Pshot 55ystem 56400.0 True 56400.0 True GroundControlStation_xMission_altitude_in=15000.0to50000.0,levels=8 66200.0 True GroundControlStation_xMission_altitude_in=15000.0to50000.0,levels=8 66400.0 True Gesign_type: full_factorial 66400.0 True Gesign_type: full_factorial 66400.0 True For Fore_doc: yes 66400.0 True Fore perform_doc: yes 72000.0 True Results over time by combining trade studies for each requirement 72200.0 True Results over time by combined with the others using ND. WARHING: If a point is N/A and another is True, the combined result is N/A. Your requirem [0.0 N/A 100.0% of the 11800.0 N/A 11800.0 N/A 2500.0 N/A 25200.0 N/A 12600.0 N/A 25200.0 False <td< td=""></td<>
Requirements Requirement #1 The GroundControlStation_x_Mission shall have a Pkill that is greated	er than 0.8 while the time is greater than to 43200.0	66400.0 False 72000.0 False 75600.0 False 72000.0 False 72000.0 False 72000.0 False 72000.0 False Requirement 1 across trade studies held true 0.0% of the time Requirement 1 across trade studies held true 0.0% of the time when applicable Requirement 1 across trade studies was N/A 56.5217391304% of the time Subsystem

SoS Trade Studies

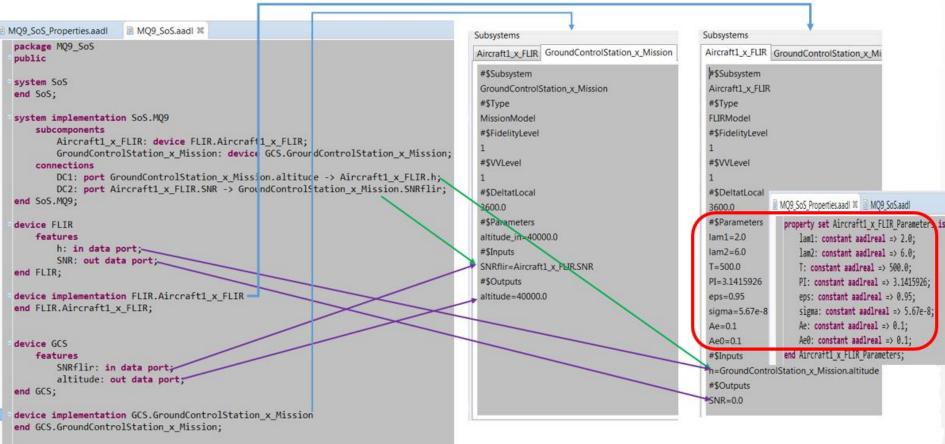
• Operate over the entire SoS and perform full simulations for each point. DOE, Monte-Carlo, and single variable optimization is available.



SYNAPTI**CAD**

AADL Integration

• Simulation models are architecturally analogous to AADL language.

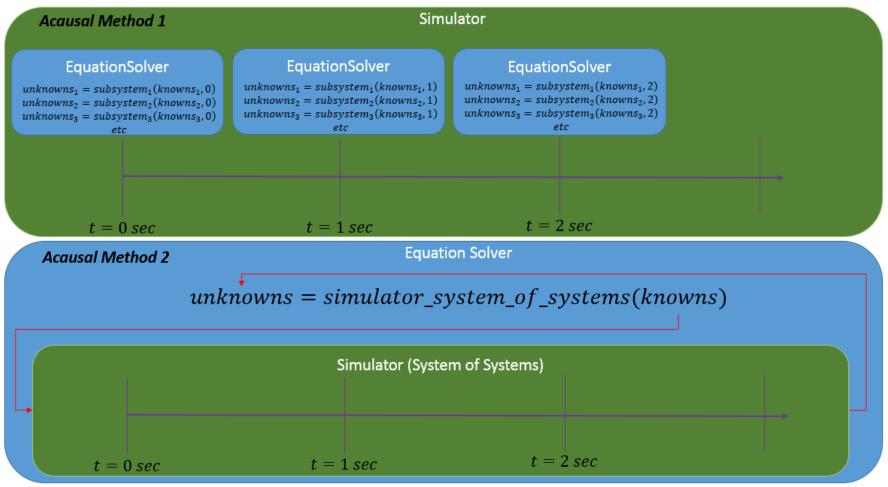


end MQ9_SoS;



Acausal Solver/Driver

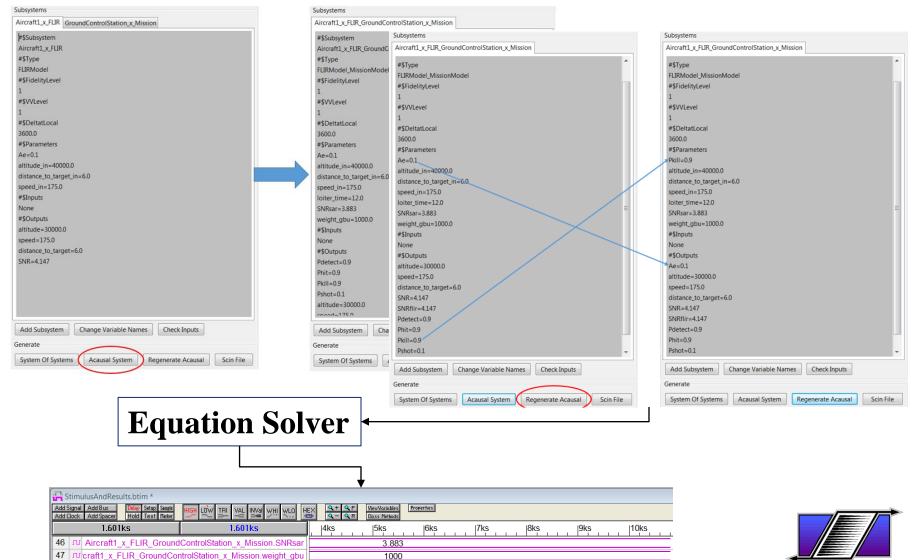
• Acausal simulation means that what we consider an input or output is not fixed. All models are solved as a system of equations using two methods:





Acausal Method 1

• Each system is rendered as an equation to be solved at every timestep. The simulator is the driver and the equation solver runs behind the scenes:



0.17022134363

SYNAPTI**CAD**

48

Aircraft1 x FLIR GroundControlStation x Mission.Ae

Acausal Method 2

• The entire SoS is viewed as an equation to be solved over the entire span of time of the simulation. The equation solver is the driver and the simulator runs behind the scenes.

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SolverCAD C:/A/PythonWork/solvercad	d/engine/Exam	npleProblems/I	MQ9AGS_b.scin					
File Help								
Simulator Equation Solver								
			$fx \land fx \land fx$	-		?		
New Open Save Save Guess Errors Solve	Sort Adjust	Check Solve			Window Tab Lock H	lelp About		
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Some Observations

- Scale up.
 - Human scalability: our ability to see, understand, and manipulate large SoS models.
 - Computational scalability: Multiple nested engineering models, solved iteratively by equation solver, are possible. Trade studies make this worse.
- "Explosion" of data caused by trade studies.
- English requirements are backed up by requirements expression through a computer language (i.e. Python).
- Requirements modeling can be enforced through equation solver.
- The acausal capability allows for many scenarios without having to rebuild the model. Inputs/outputs can be switched.
- This tool is designed to be linked from 3rd party systems engineering tools such as AADL or SysML.



Backup Slides



1. Eqn. Based Model Creator

- A general purpose model-creation environment for engineering analysis. Under development.
- Solves any system of nonlinear simultaneous equations.
- Manages the core numerical library to achieve robustness.
- Generates Python functions to use in simulation code.
- Uses a library concept for storing functions for later use.

ile Help					
Equation Solver					
Solve any system of simultaneous equations					
Click here to generate a scriptwrapper for this example Click here to generate a function for this example Function return value? p2 Use base units in generated function? Base_Units UserInput_Units	#EquationsBegin v=(mu/(Rearth+z))**0.5 T=((20+P)(w*0.5))*(Rearth+z)**1.5 h=(Rearth+z)v energy=-10*mu/(20*(Rearth+z)) t=(h*3/mu*2)*Theta LocalFunctions.Cos(Ninety-ThetaShade2) ThetaShade1=ThreeSixty-ThetaShade2 <	-Rearth/(Rearth+z)	 Soluti T = 58 Theta Theta Theta Theta energy fakevi h = 52 		
Get hints for filling out form:	#KnownsBegin mu=2986E14 m*3/sec*42 PI=3.1415926 dimensionless Reath=6378000.0 m z=6000020 meter t=10.0 sec NineEy=1.5707963267949 rad ThreeSity=6.2818530717959 rad ispos=1.0 dimensionless	 #GuessesBegin v:1000.0.1000.0.1,m/sec T.4800.0.8400.0.1,sec h.10E10.264E11,1.m*2/sec energy-50.143.0.1m*2/sec*2 theta.0.0175.53.71,rad ThetaShade2.0.0175.15.71,rad ThetaShade1.4716.281,rad is in sun.0.0.10.1,dimensionless fakevan.0.0.0.1,dimensionless 	*	if(thetash2 > 0.0); return 1.0 else: return 0.0 def IsinSun(theta,thetash1,thetash2); if(theta < 0.05 and theta >= 0.0); return 0 else: return 1	Ē
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marker_instance.pub- title=the big one legend_list=red,blue xlabel=x axis ylabel=y axis y/label=z axis	LocalFunctions.Cos,dimensionless LocalFunctions.InShade,dimensionless	UseRandomGuesses True NumRandomGuesses 10	* = *	Encine=1.0E-7	* !!! *
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Graph Title Plot Graph			_		
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2. System Builder

A GUI that helps you build, connect, and modify sub-system models for simulation.

- Create system models from a library of prebuilt subsystems.
- Create subsystem models from equation solver and external tools.
- Publish subsystems to library.
- Easily replace subsystems with higher/lower fidelity ones.

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Change Variable Names Check Inputs Edit Calculations / Utils File Edit Library Model Select Model Above Edit System Model	jel



2. System Builder, cont.

Includes a feature to help you edit calculations or link to them from external tools.

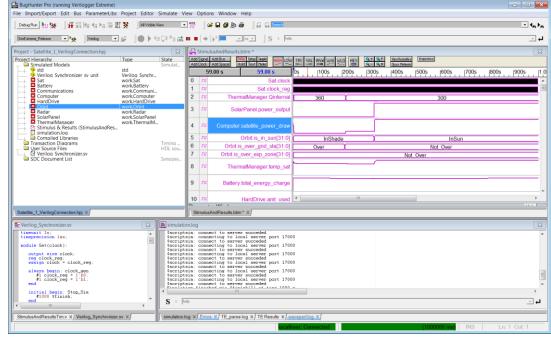
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program.	Insert Python Code		except NameError:	
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	for while		return int_val	
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3. System Simulator

The system simulator combines a high-performance compiled-code SystemVerilog simulator with a Python interpreter to enable engineering level modeling of real world systems.

- Timing diagram with simulation results
- Generated SystemVerilog code.
- Hierarchical view of subsystems and components.
- Full IDE including single step debugging, breakpoints, etc.
- Design browsing & navigation.
- Various output formats

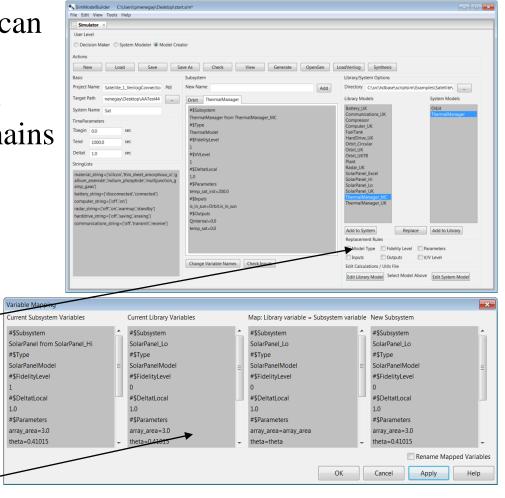






Multifidelity Modeling

- Models of different fidelity can be switched on the fly.
- As the project advances, the simulation environment remains in place, and maintains connectiveity with previous models.



Replacement rules for switching model fidelity

Variable mapping to ensure continuity between models



Model Libraries

• Subsystem model library.

Builder.

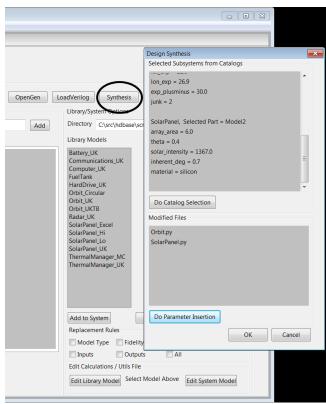
- Orbit calculations, solar panel, battery, etc. are publishable and retrievable from library.
- Function library for equation solver.
 - Generated functions can be accessed by System

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HardDrive_UK	11/13/15 2-39 PM	File folder	18 JD relative to base = 7287.9
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Communications_UK	11/13/15 2-38 PM	File folder	20 lon_gnd = 241.81 21 gnd plusminus = 30.0
Battery_UK	11/13/15 2:38 PM	File folder	21 gnd_plusminus = 30.0 22 lat_exp = 22.9
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Synthesis

- Compares simulation subsystems with a catalog of parts.
 - User has presumably optimized the subsystem and now wants to select hardware.
 - Software will choose the closest part from catalog and resimulate.





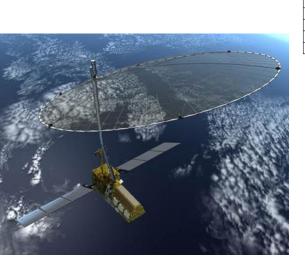
Orbit ###### PAR mu=398600.0 PAR Rearth=6378.1 PAR z sat perigee=500.0 PAR z sat apogee=510.0 PAR i=40.0 PAR Omega=30.0 PAR omega=20.0 PAR JD base=2450000.0 PAR JD_relative_to_base=7287.9 PAR lat gnd=34.2 PAR lon gnd=241.81 PAR gnd plusminus=30.0 PAR lat exp=22.9 PAR lon exp=26.9 PAR exp_plusminus=30.0 PAR theta=0.0 INP None OUT true anomaly=0.0 OUT lat=0.0 OUT lon=0.0 OUT is in sun=False OUT is over gnd sta=False OUT is over exp zone=False OUT altitude=505.0

Satellite Model

Sat

Satellite circles the earth in a standard elliptical orbit. It's mission is to collect earth data over an experimental zone and download it to a ground station at another location. It charges a battery in the sun and depletes the battery in the shade. The simulation objective is to understand if the subsystems are sized properly.





SolarPanel

PAR material='silicon'.material string

PAR array_area=3.0

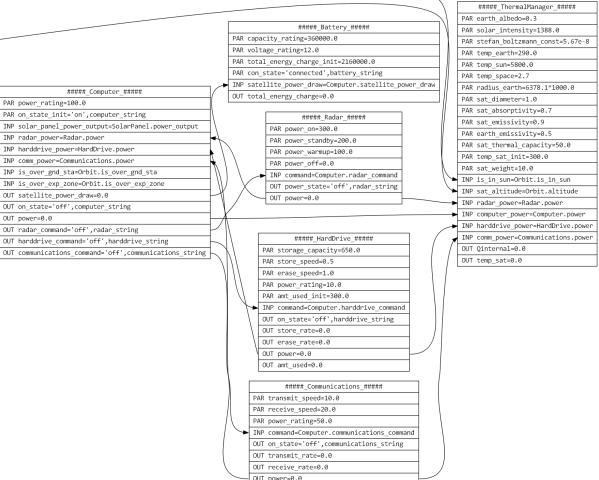
PAR theta=0.41015

PAR inherent deg=0.77

OUT power_output=0.0

PAR solar intensitv=1367.0

INP is in sun=Orbit.is in sun



NASA / JPL

Results

0.000ms Oks Sat clock Sat clock reg true_anomaly Orbit.lat Orbit.lat Orbit.lan s_in_sun[31:0] (n:) and_sta[31:0] () exp_zone[31:0] () exp_zone[31:0] () nager.Qinternal () 300 te_power_draw	InSun Not Over ver) Over)	(InShade) Not Over	InSun (Over)	10ks 11ks 11519201 m 0 0 0 0 0 0 0 0 0 18.6806781 220.532489 19.10Shade InShade InShade 0 0 0 0 0 0	7655017) InShade) InSun (Over) Not Over
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-Battery slowly drains to 0

Solar Panel does not recharge it when exposed to sun Ie, the Solar Panel is undersized. Battery is oversized.



Results, cont.

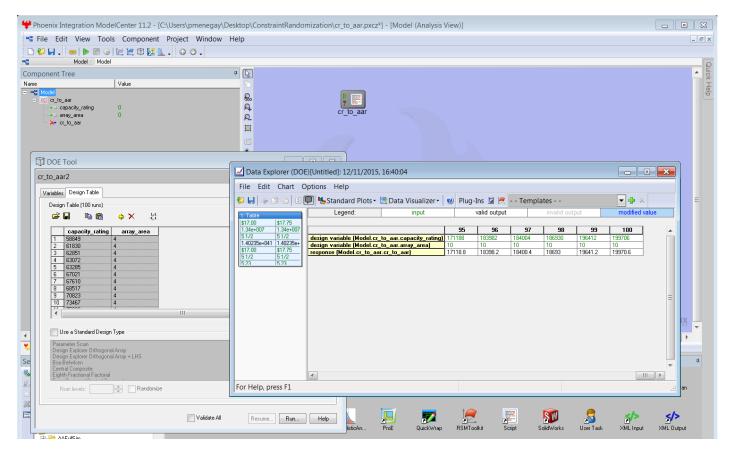
- One way to vary the solar panel / battery size is to use constrained randomization.
- Solution was to increase the solar panel area from 3.0 to 4.0 m**2 and decrease the battery capacity from 360,000 to 60,000 amp-sec.

Constrain_Batt_SolarPanel.sv	X
<pre>program Constrain_Batt_SolarPanel;</pre>	
class Constrainer; rand integer cr; rand integer cr; rand integer ca;	
<pre>constraint c1 { cr_to_aar < 20000;} constraint c2 { cr_to_aar > 10000;}</pre>	
<pre>constraint c3 { cr >= 55000;} constraint c4 { cr <= 200000;}</pre>	
<pre>constraint c5 { aar >= 4;} constraint c6 { aar <= 10;}</pre>	
<pre>constraint c0 { cr_to_aar == cr / aar;} endclass</pre>	
<pre>initial begin Constrainer obj = new(); int wile; furtie(vie)(=:(::::::::::::::::::::::::::::::::::</pre>	<pre>cr_to_aar = %0d*,obj.cr,obj.aar,obj.cr_to_aar);</pre>



Results, cont.

• This could also have been achieved by driving the simulator from a ModelCenter DOE.





Overall Results

- Once engineering models were made, system integration was fast, 1-2 days for this case.
 - Model libraries were key.
- Provision for multi-fidelity model switching allowed project to remain within a single environment throughout its life.
- Scalability tests on a simple vehicle object lends credence to the SystemVerilog approach.
 - SystemVerilog can simulate up to memory limits of computer. 18 million vehicles for 32-bit and 40 million for 64 bit.
 - SimPy by contrast could simulate 900,000 such objects.
- Runs could be made faster by using event-driven simulation. A 10 fold speed up was achieved this way.
 - Important for long run times over the life of the system.

We thank the NASA SBIR program for sponsoring this work. Contract NNX15CP26P.

