

INTEGRATED MODEL-BASED SYSTEMS ENGINEERING (MBSE) APPLIED TO THE SIMULATION OF THE OSIRIS-REX PHOENMISSION 2018 International Users' Conference Annapolis, Maryland

> Phathom Donald Systems Engineer

LOCKHEED MARTIN

OSIRIS-REX MISSION

Overview Challenges Objectives Approach Modeling Simulating Results Reflections Future Work



Video Credit: NASA/Goddard Space Flight Center



OSIRIS-REX MISSION OPERATIONS



Results

- Need to avoid sun in the Thermal KOZ and in the +Z area ightarrowof the spacecraft.
- Thermal constraints assert sun cannot be in Thermal KOZ \bullet past a certain duration threshold.



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Future Work

OBJECTIVES

Previous Operations Process

- Use of GNC prediction software that provides review of constraint violations.
- Run through SoftSim testbed.
- Cannot easily identify spacecraft constraint violations until mid-development.

New Operations Process Objectives

- Rapidly evaluate various trajectories for thermal constraint violations to identify preferred mission trajectory.
- Provide quicker, more flexible approach for assessing geometry constraints during early stages of mission planning.
- Efficiently track variables during proposed OSIRIS-REx trajectories.



APPROACH

Overview Challenges Objectives Approach Modeling Simulating Results Reflections Future Work



Systems Tool Kit (STK)



Data Explorer

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OSIRIS-REX SYSTEM ARCHIERERMODE Laptures:

Default Value

Overview Challenges Objectives Approach Modeling Simulating Results Reflections Future Work



Parametrics

Name



Structure



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MBSEPAK (MBSE ANALYZER)

Overview

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Results

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- The constraint block in the architecture model points to ModelCenter workflows using MBSE Analyzer.
- MBSE Analyzer within MBSE Pak solves the parametric diagram by linking it to the model in ModelCenter that consists of scripts and the STK component.



Overview Challenges Objectives Approach Modeling Simulating Results Reflections Future Work

SYSTEMS TOOL KIT (STK)

- To express the Sun vector's azimuth and elevation in reference to the Body Axes, the vector is projected onto the Body XY plane, creating the red "SunOnXY" vector.
- The angle between SunOnXY and Body X is the "SolarAzimuth". The angle between SunOnXY and Body Z is the "SolarElevation".



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MODELCENTER WORKFLOWS

Overview

Challenges

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Modeling

Simulating

Reflections

Future Work

Results



 The scenario results are linked to scripts defined in ModelCenter for determining any constraint violations.

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SIMULATION PROCESS



Overview

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Results





5. Retrieve parameter values from STK.

1. Enter simulation settings and constraints.



7. Display simulation results for each time step.

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analysis tools.

2. Initiate simulation from **MBSE** Analyzer.







3. Step through the mission simulation.

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SIMULATION RESULTS & REQUIREMENTS

	MANUAL SCROLL	1	2	3	4	5	6	7	8	9	10	11	12	13
	Analysis ID	GetStates												
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	Analysis Run	1	2	3	4	5	6	7	8	9	10	11	12	13
	M.O.O.AnalysisStartTime (String)	12 Nov 20												
	M.O.O.AnalysisStopTime (String)	13 Nov 20												
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Overview	M.O.O.ElapsedTimeSec (Integer)	0	3600	7200	10800	14400	18000	21600	25200	28800	32400	36000	39600	43200
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Challenges	M.O.O.ZKOZ_Count (Integer)	0	0	0	0	0	0	0	0	0	0	0	0	0
Ŭ	M.O.O.isTimeRemaining (Boolean)	true												
	M.O.O.NewCurrentTime (String)	12 Nov 20												
Objectives	M.O.O.o.BennuRange (km)	164.70742	164.42559	164.14434	163.86367	163.58359	163.30411	163.02525	162.74699	162.46937	162.19237	161.91601	161.64031	161.36526
Objectives	M.O.O.o.EarthRange (km)	129264246	129255271	129246277	129237265	129228234	129219184	129210116	129201028	129191923	129182798	129173655	129164493	129155313
-	M.O.O.o.SAP_Angle (degree angle)	21.872639	21.992132	22.112272	22.233064	22.354509	22.476612	22.599374	22.722799	22.846890	22.971649	23.097080	23.223185	23.349967
	M.O.O.o.SolarAzimuth (degree angle)	174.98344	174.98358	174.98373	174.98387	174.98401	174.98415	174.98429	174.98443	174.98456	174.98470	174.98483	174.98496	174.98509
Approach	M.O.O.o.SolarElevation (degree angle)	·67.121481	-67.001988	-66.881847	-66.761054	-66.639608	-66.517504	-66.394741	-66.271315	-66.147224	-66.022464	-65.897032	-65.770926	-65.644143
Apploach	M.O.O.o.SolarRange (km)	156443804	156424042	156404285	156384534	156364788	156345047	156325311	156305581	156285856	156266137	156246423	156226714	156207010
	M.O.O.o.SPE_Angle (degree angle)	66.364547	66.371714	66.378885	66.386059	66.393237	66.400419	66.407605	66.414795	66.421988	66.429185	66.436387	66.443592	66.450801
	M.O.O.o.TKOZViolationCount (String)													1
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Simulating	M.O.O.o.ZKOZViolationDuration (String)													No Violations
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	M.O.O.o.ZKOZViolationStop (String)													No Violations
	M.O.O.o.ZoneInSun (String)	Thermal KOZ												
Reculte	M.O.O.o.e.s.Solar_Incidence_Angle (degree angle)	155.12148	155.00198	154.88184	154.76105	154.63960	154.51750	154.39474	154.27131	154.14722	154.02246	153.89703	153.77092	153.64414
nesuits	M.O.O.o.e.s.Solar_Incidence_Angle (degree angle)	155.12148	155.00198	154.88184	154.76105	154.63960	154.51750	154.39474	154.27131	154.14722	154.02246	153.89703	153.77092	153.64414
	M.O.O.o.g.NadirSun_GNC_PointingMode (String)	Can Use												
Reflections	M.O.O.o.g.s.STA_BennuViolationStatus (String)	No Violation												
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	M.O.O.o.g.s.STA_SunViolationStatus (String)	No Violation												
Future Work												•		

- System-level and subsystem-level states captured in value properties.
- Requirements verification captured in value properties. ightarrow
- Values stored at each time step and displayed in Data \bullet Explorer.



Overview Challenges Objectives Approach Modeling Simulating Results Reflections Future Work

REFLECTIONS

MBSE Advantages

- Formal, accurate systemlevel model capture.
- Early identification of requirements issues.
- Early, and on-going requirements and design verification.
- Improved impact analysis of requirements changes.
- Interconnectivity and reuse of existing models to support system design.
- Rapid re-evaluation when design changes occur.

Challenges Encountered

- Could not express time in UTCG without STK Object Model. (resolved in STK11)
- No requirements verification at each time step.
- Dot notation not allowed on parametric diagrams.

Lessons Learned

- The STK Programming Interface allows for great flexibility.
- Collaborating with vendor tech support is imperative.

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FUTURE WORK

- Extend the system-level model
 - Include downlink duration and momentum buildup
- Extend and refine the behavioral and analysis models
 - Improve approach for plot generation



- Enable sensitivity analysis and design optimization
- Implement analysis integration for NASA's Lucy mission

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Future Work

SIMULATION SETTINGS & THERMAL CONSTRAINTS • Simulation time

settings and system thermal constraints are captured in the system model.

• This facilitates requirement and constraint changes for efficient impact analysis.



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Results

STRUCTURAL DIAGRAMS bdd [Block] OREX_Mission [Mission Level Overview] «block» 品 **OREX** Mission Vehicle Level Overview petStates : GetStates incrementTime : IncrementTime AnalysisStartTime : String = 12 Nov 2018 00:00:00.000 AnalysisStopTime : String = 13 Nov 2018 00:00:00.000 **Overview** StepSize : Integer = 3600 New CurrentTime : String BapsedTimeSec : Integer IntervalSize : Integer = 43200 **Mission Level** IntervalNumber : Integer = 1 is TimeRemaining : Boolean TKOZ_Count : Integer = 0 Challenges ZKOZ_Count : Integer = 0 **Objectives** orbit osiris rex. att sch. thrm cnstr «block» «block» «block» «block» **OREX** Spacecraft Orbit Attitude Scheme ThermalConstraints SolarAzimuth : deg ZoneInSun : String ZKOZViolationStart : String AttitudeSegment : String OSZ Az Max : Real OSZ_Az_Max : Real OSZ_B_Mn : Real OSZ_B_Max : Real ZKOZ_Az_Min : Real ZKOZ_AZ_Max : Real ZKOZ_B_Mn1 : Real ZKOZ_B_Mn2 : Real Approach SolarBevation : deg SolarRange : km EarthRange : km Dow nlinkState : Real Dow nlinkDuration : sec TKOZViolationStart : String BennuRange : km SPE_Angle : deg SAP_Angle : deg TKOZViolationStop : String ZKOZViolationStop : String «block» Modeling TKOZViolationDuration : String ZKOZViolationDuration : String TKOZ_Az_Min : Real TKOZ_B_Min : Real TKOZ_B_Max : Real **OREX** Space craft TKOZViolationCount : String ZonelnSun : String ZKOZViolationCount : String KOZ Duration Threshold Integer ZKOZViolationStart : String Dow nlinkState : Real Dow nlinkDuration : sec Simulating TKOZViolationStart : String TKOZViolationStop : String ZKOZViolationStop : String TKOZViolationDuration : String ZKOZViolationDuration : String TKOZViolationCount : String ZKOZViolationCount : String eps gnc pavload avionics comm «block» «block» «block» «block» «block» «block» tagsam «sun sensitive component» EPS GN&C Communication Payload Avionics **Reflections** TAGSAM adirSun_GNC_PointingMode : String «block» src «sun sensitive components «block» «block» «sun sensitive component» «block» ensitive component» «block» «sun sensitive component» «block» SRC mcam cdh hga sa1 SolarArray «sun sensitive component» Future Work MapCam C&DH HGA Star Tracker «block» Vehicle Level Default Array Position 1 : deg = 90.0 mech therm et Default Array Position 2 : deg = 45.0 Array Position : deg Solar Incidence Angle : deg «block» «sun sensitive compo Mechanisms & Therma «block» «block» STA_SunViolationStatus : String ent» mga sun sensitive components sun sensitive component sa2 STA BennuViolationStatus : String STA_MoonViolationStatus : String STA_EarthViolationStatus : String PolyCam PDDU MGA Pow er : W «block» prop lga1 Propulsion «block» «sun sensitive compon «block» «block» apu «block» «block» «sun sé nsitive compo nsitive components lga2 sun sensitive component» mimu REXIS PAPU LGA 30 A-Hr Battery MIMU «block» «sun sensitive component» cam eblock: rw a sun sensitive components Sam Cam RWA «block: ola «block» sun sensitive component «sun sensitive component» lidar OLA GN&C LIDAR «block» nc1 ovirs eblock: «sun sensitive component» «sun sensitive component OVIRS nc2 NavCam «block» otes «sun sensitive component: OTES

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PARAMETRIC DIAGRAM

- Using MBSE Pak, value properties are bound to a constraint block that links to a model in ModelCenter that contains scripts and a STK component.
- Inputs to STK:
 - Analysis Start Time
 - Analysis Stop Time
 - Time Step Size
- Outputs from STK
 - Solar Elevation
 - Solar Azimuth
 - Solar Range
 - Earth Range
 - Bennu Range
 - SAP Angle
 - SPE Angle
- Outputs from ModelCenter
 - KOZ in Sun
 - Duration of thermal violations



TKOZ_B_Mb:

TKOZ_B_Max : Real



MAIN SIMULATION LOOP

OverviewChallengesObjectivesApproachModelingSimulatingResultsReflectionsFuture Works



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