Making Debris Avoidance Decisions for ESMO's EOS Mission Set

SSA Operator Conference - Denver, CO

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Agenda

- **Terra Mission Overview**
- **Orbital Constraints**
- **High Level Aspects of CA Process**
- **Notification Timelines**
- **Aura Close Approach → Creation of DAWG**
- **Process Improvements**
  - Reduced Maneuver Execution Time
  - Identified Risk Thresholds
  - Identified Information Needed to make decision
  - Generated & Documented Process Flow
- **Future Plans & Challenges**
- **Backup Slides**
  - Role and Responsibilities

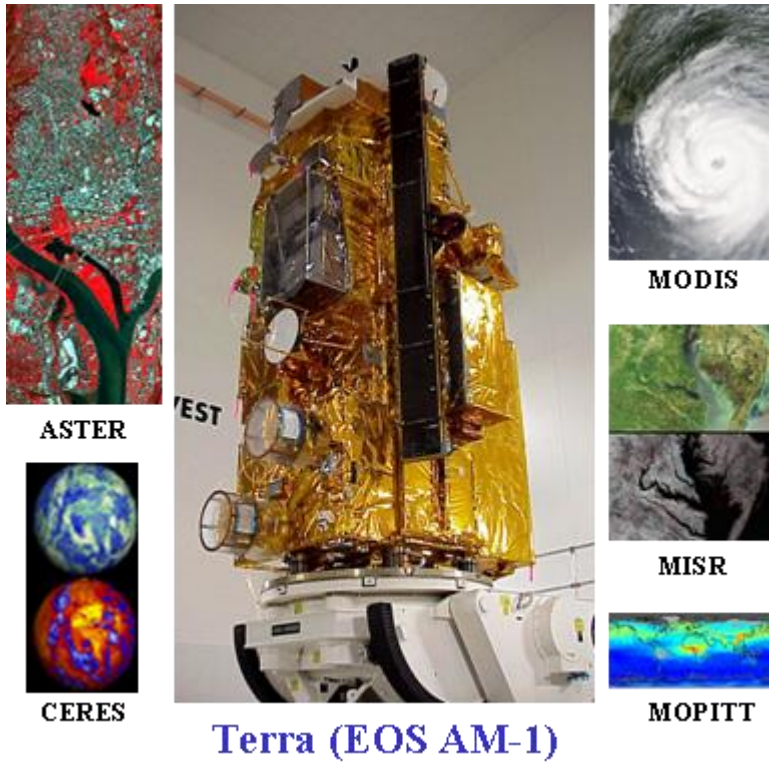
Terra Mission Overview

Terra Features

- **Launch Date:** *December 18,1999 (Atlas IIAS, VAFB)*
- **Orbit:** ***705 km, Sun-synchronous polar, 98.2º Inclination, 10:30 AM MLT descending node***
- **Instrument Payload:**
  - **ASTER (*SWIR*, TIR & VNIR) -** *Advanced Spaceborne Thermal Emission and Reflection Radiometer* (Japan)
  - **CERES (Fore & Aft) -** *Clouds and the Earth's Radiant Energy System* (USA – Langley)
  - **MISR -** *Multi-angle Imaging Spectro-Radiometer* (USA – JPL)
  - **MODIS -** *Moderate Resolution Imaging Spectro-radiometer* (USA – GSFC)
  - **MOPITT -** *Measurement of Pollution in the Troposphere* (Canada)
- **Project Management:** *Earth Science Mission Operations (ESMO)*
- **Spacecraft Flight Operations:** *Contracted by GSFC to Honeywell / ASRC/JBS/AIMM team and supported by NASA NENs and TDRSS*
- **Instrument Operations and Science Data processing:** *Performed at respective Instrument Locations where developed*
- **Mission Duration:** *Successfully completed Prime mission of 5 years. Currently in Extended Operations.*
- **Distributed Active Archive Centers:** *LP DAAC – MODIS, ASTER; Langley DAAC – CERES, MISR, MOPITT*

Science

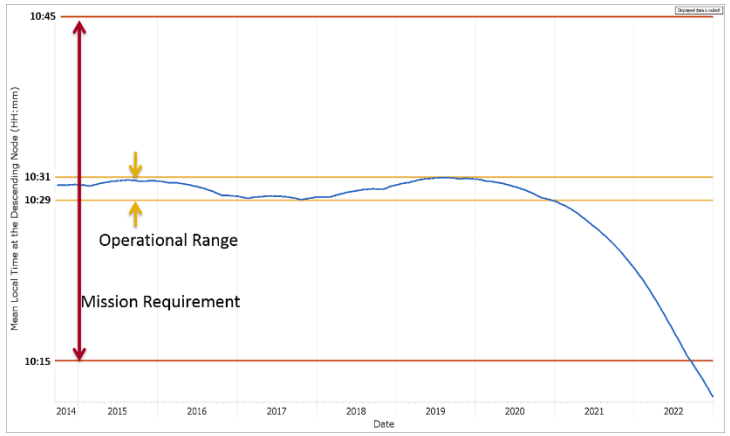
- *The primary objective of the Terra Mission is to simultaneously study clouds, water vapor, aerosol, trace gases, land surface and oceanic properties, as well as the interaction between them and their effect on the Earth's energy budget and climate.*

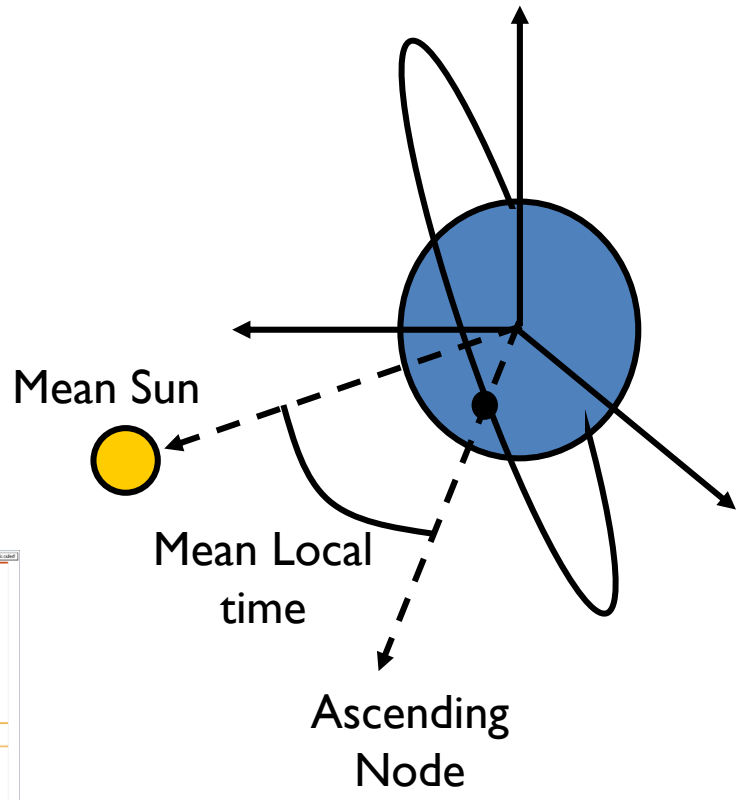


EOS Mission Orbit Constraints

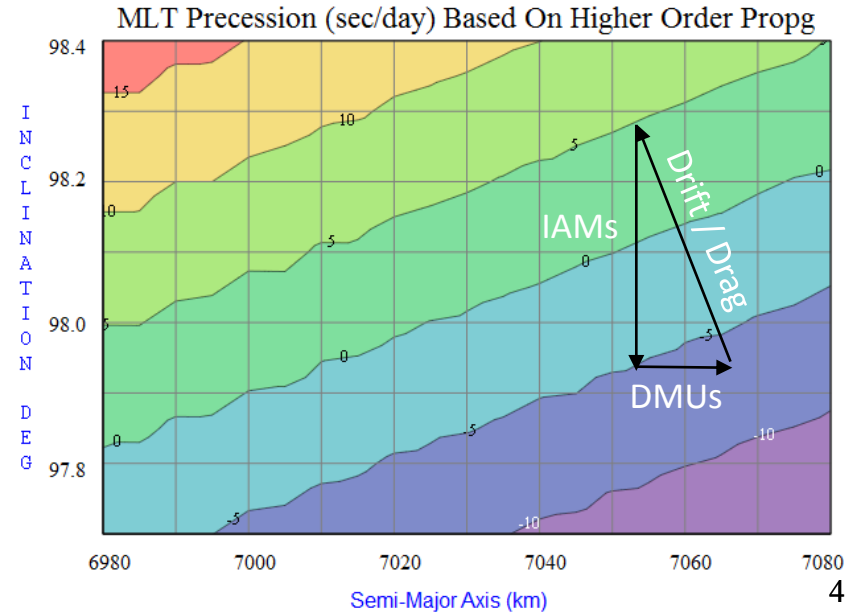
Understanding MLT

- **The orbit is designed to maintain a nearly constant angle between the Ascending or Descending Node (AN/DN) and the Mean Sun**
- **This angle is measured in hours and is called the Mean Local Time (MLT)**
- **An MLT of 12:00 means the angle between the Node and Mean Sun is zero**
- **An MLT of <12:00 means the Node crossing appears to the west of the Mean Sun**
- **The Terra MLTDN control box is 10:29 – 10:31**





- **Luni-solar gravitational perturbations (from Sun and Moon) on an orbit cause the inclination to drift away from the ideal inclination**
  - This causes the nodal rate to move away from the ideal 360°/year resulting in Mean Local Time drift.
  - Inclination maneuvers are periodically performed to maintain the nodal rate around the desired value in order to keep the MLT within limits

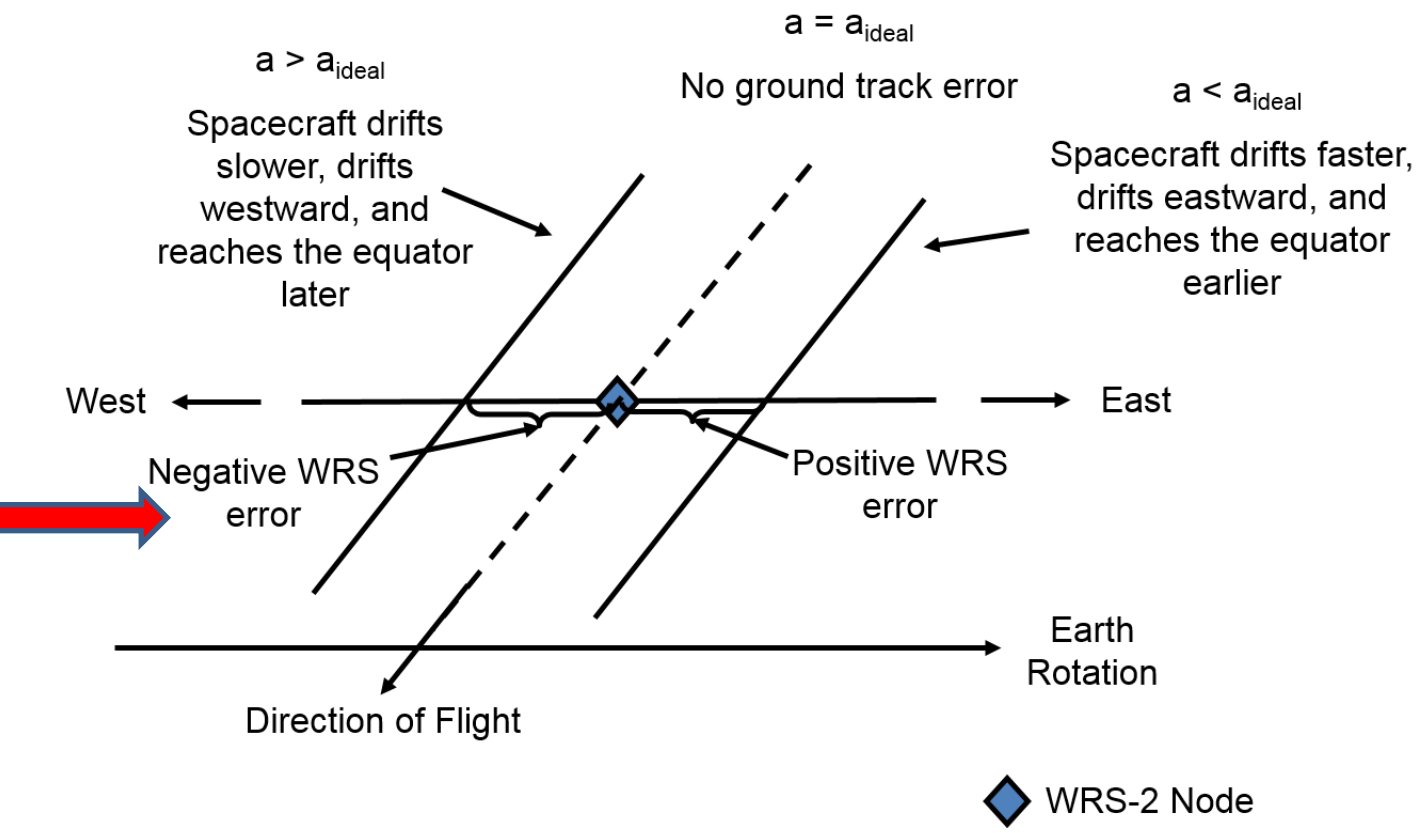


EOS Mission Orbit Constraints

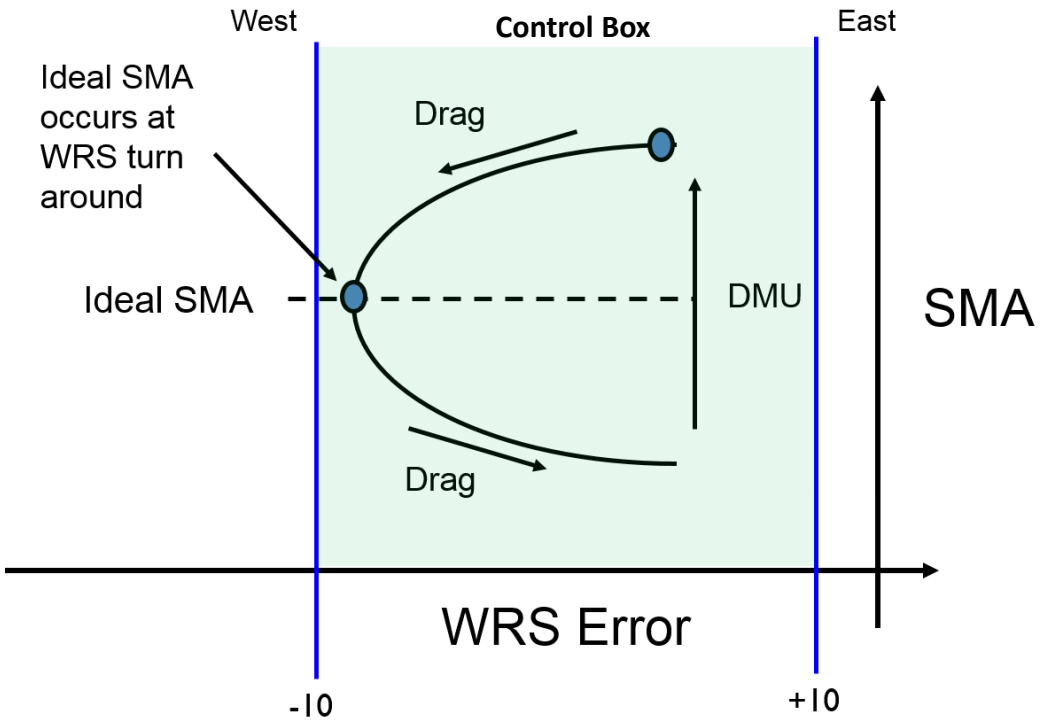
WRS-2/Ground Track Maintenance

- **An ideal semi-major axis (SMA) must be flown in order to fly the WRS-2 ground track**

Top View

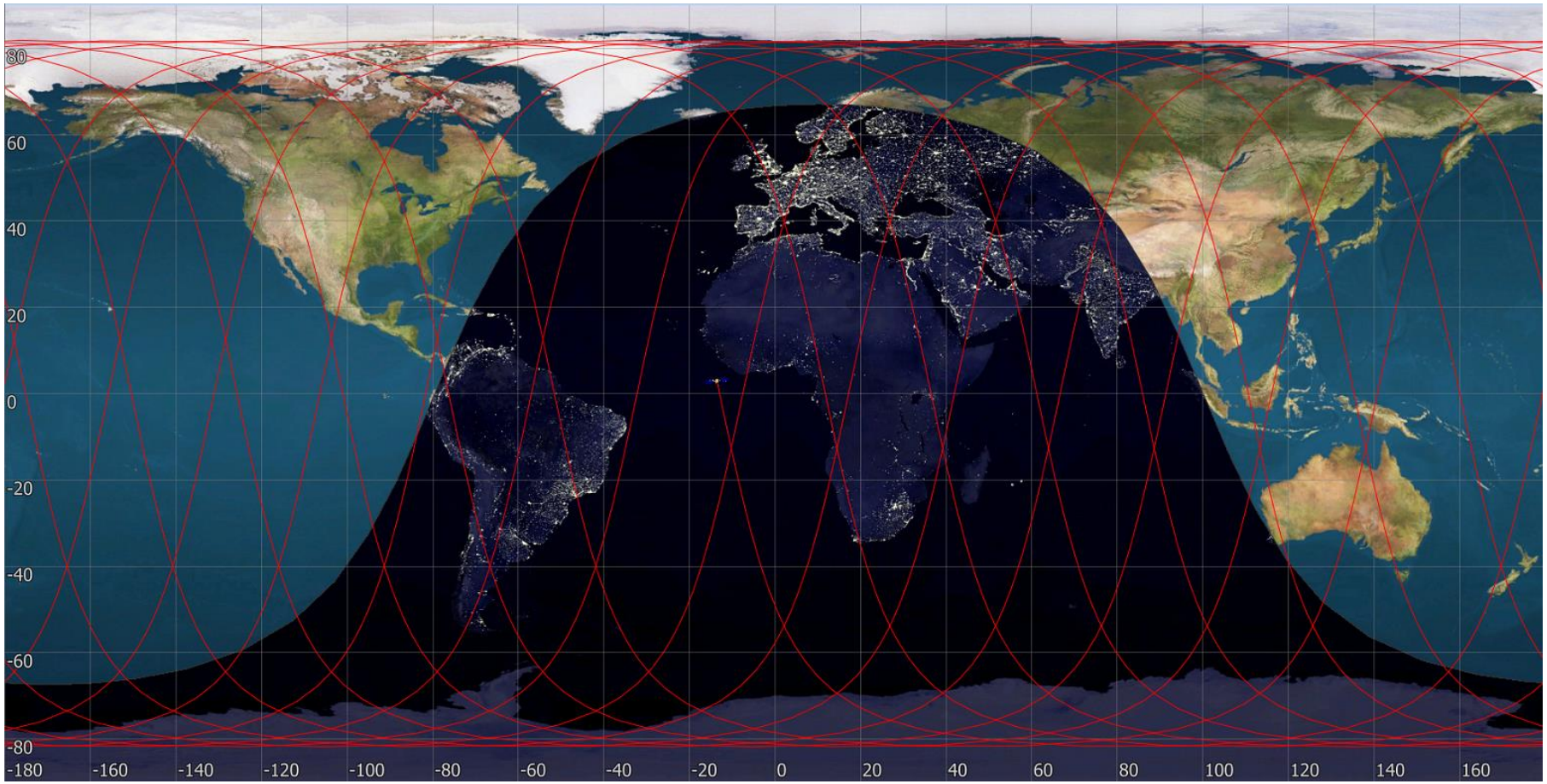


Side View



EOS Mission Orbit Constraints

16 Day Repeat Cycle



- Flying at 705km sun-synchronous orbit provides the benefit of repeating the same exact ground track every 16 days
- Both the **Altitude** and **MLT/Inclination** have to be controlled to achieve this benefit

Highly Level Aspects of CA Process

Mission Director's Perspective

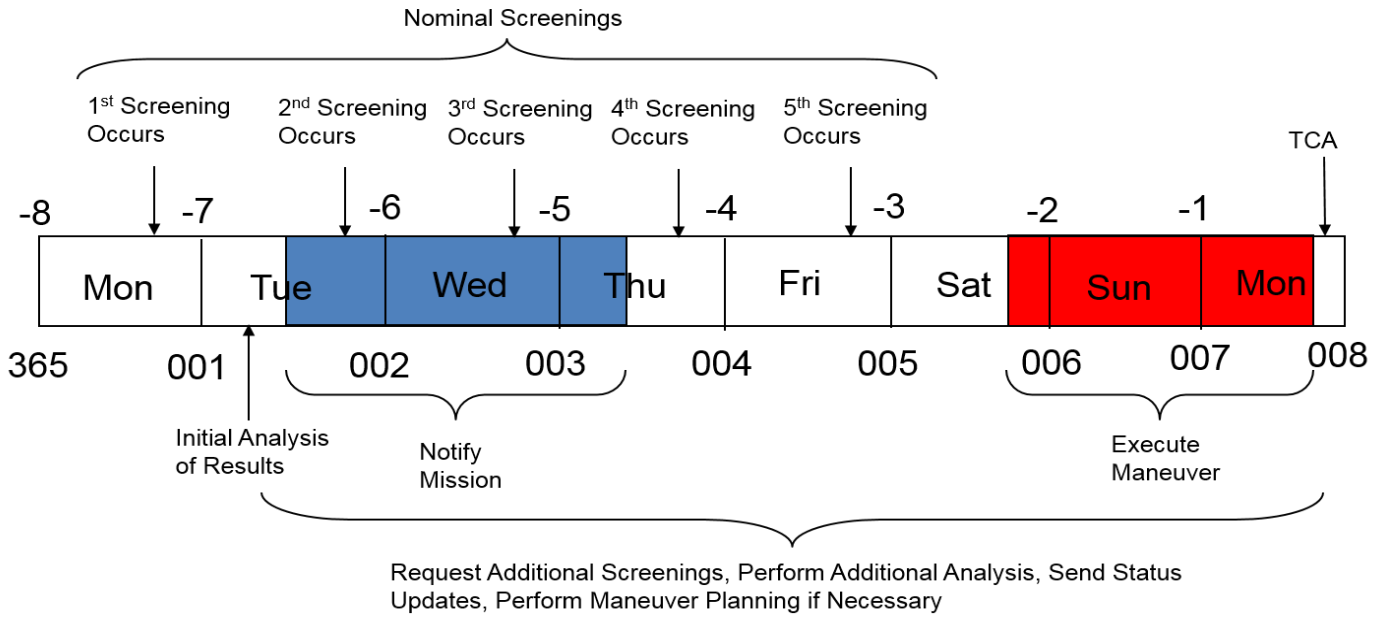
- **Sensor data from JSpOC** — Information Source
  - Routine Screenings
  - Tasking Prioritization
- **Data Analysis** — Information Source
  - Understanding confidence in solution
  - Assessing risk
  - Identifying burn times & duration
- **Maneuver Planning** — Readiness for Action
  - Contact Scheduling
  - Product Generation & Delivery
    - Ephems & Planning Aids
  - Coordination with Instrument Operations Team
  - Identifying options within mission/science constraints
- **Maneuver Execution** — Decision for Action
  - Use propulsion system to impart delta-v on spacecraft
  - Returning to nominal science data collection state

Drag Make-Up -> Debris Avoidance Maneuver Concept

- **EOS Missions fly in repeat ground track orbit at 705kms**
- **Spacecraft designed to perform Drag Make-Up (DMU) and Inclination Maneuvers**
  - Retrograde capability not part of nominal maneuver set
- **Drag Make-Up Maneuvers therefore used to mitigate debris risk**
  - Raise altitude (can only go up, one direction)
- **Differences in DMU & Debris Avoidance Maneuver (DAM) concepts are significant**

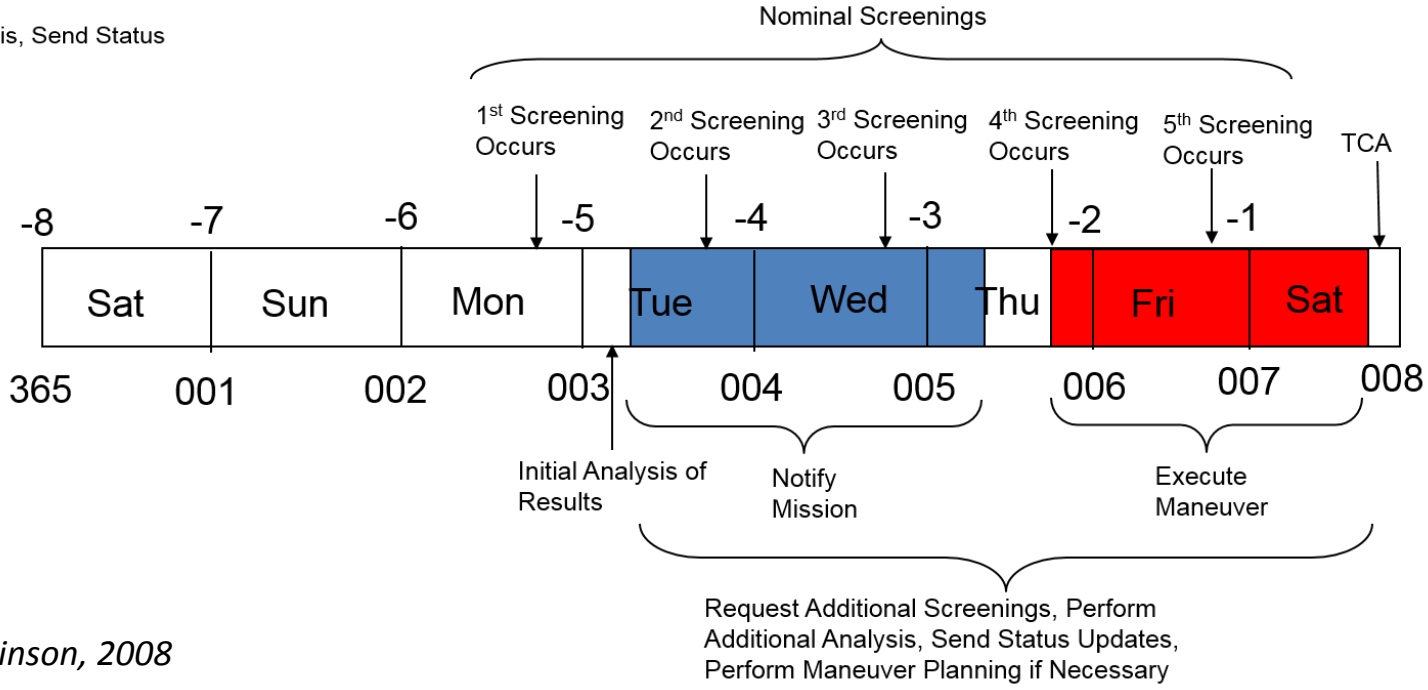
	DMU	DAM
Purpose	Maintain Orbit Altitude	Avoid Debris
Notification Time	Several Weeks	Few Days or Less
Ops Mentality	Routine, Methodical	Urgent, Quick Turnaround
Contingency Action	Reschedule	Health & Safety Concern
Burn Duration	Well Defined	Variable
Burn Options	One	Multiple
Execution Time	Day Shift Only, M-F	Anytime, Any Day

Generic Notification Timeline Scenarios (2008)



Well Tracked, Early Notice Secondary Object
(Stable Pc)

Poorly Tracked, Late Notice Secondary Object
(Variable Pc)



Source: Brian Robinson, 2008

Aura Close Approach Summary
June 2008 (DAM)

CA Timeline

- **Sat 6/21– Close Approach predicted for 6/27 (30m, Pc of 1:13)**
- **Mon 6/23 – CARA briefed Mission Director (8am) and FOT (11am)**
- **Mon 6/23 – Aura Close Approach (CA) Kick-Off Meeting (4pm)**
  - FDS/CARA recommends to initiate maneuver planning for **TCA – 48^{hrs}**
- **Tue 6/24 – CA/Debris Avoidance Maneuver (DAM) Meeting (9am)**
  - 4 additional updates received since kick-off meeting
- **Tue 6/24 – CA/DAM Status & Planning Meeting (4pm)**
- **Wed 6/25 – CA/DAM Status & Planning Meeting (9am)**
- **Wed 6/25 – CA/DAM Status & Planning Meeting (4pm) – CAM**
  - Pc peaks at **~48%** with minimum miss distance of ~11 meters
- **Thu 6/26 – CA/DAM Status & Planning Meeting (7am)**
- **Thu 6/26 – FOT performs DAM at 10:25am (2-second burn)**
- **Fri 6/27 – Predicted Time of Close Approach (TCA) was 11:34am**

- 6 meetings to discuss conjunction
- Pc peaked at ~48% with miss of ~11m
- Early burn planned (24-48 hours prior to TCA)

Challenges Encountered

- **Relatively short time frame to work the problem**
  - **Operational constraints that determine minimum turn-around time**
- **Spacecraft constraints that limit options**
  - **No retrograde maneuvers**
  - **Hadn't performed short duration burn**
- **Orbit Maintenance Requirements that limit response**
  - **Need to stay in control box (small burns only)**
- **Coordination with Instrument Teams**
  - **Different time zones**
  - **Reconfiguration requests via stored commands**
- **Limited Resources**

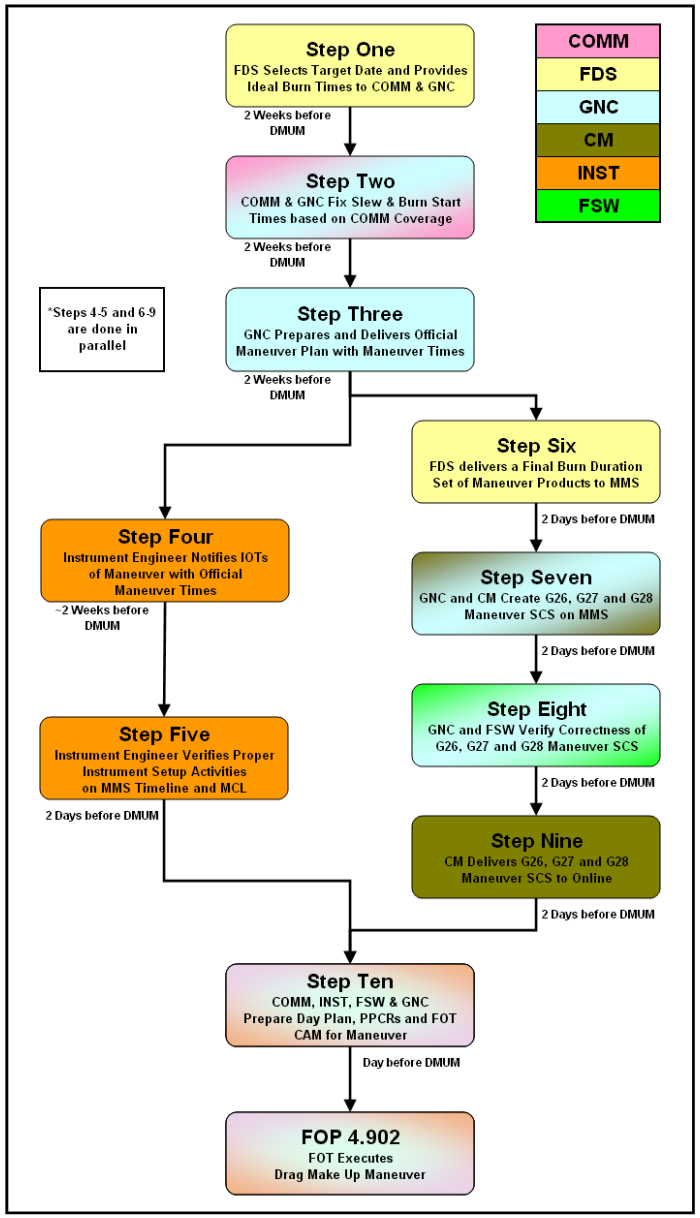
Lessons Learned

- **Need to better understand/model performance of short maneuvers**
- **Uncertainty in the secondary object may lead to the desire to wait as long as you can before performing the maneuver, in order to get as many data points as possible**
  - Forces turn-around time of planning/executing a maneuver to be very condensed
    - **Need to analyze current processes/constraints to see if turn-around time can be shortened**
- **CA and FOT teams need to better understand each other's processes**
  - Need SOPs to define CARA & FOT processes for planning/executing DAMs
  - Need to define/better understand how CARA and FOT processes fit together
- **Kicked Off Debris Avoidance Maneuver Working Group** (Flight Dynamics, FOT & CARA)

Shortening DMU Timescale for DAMs

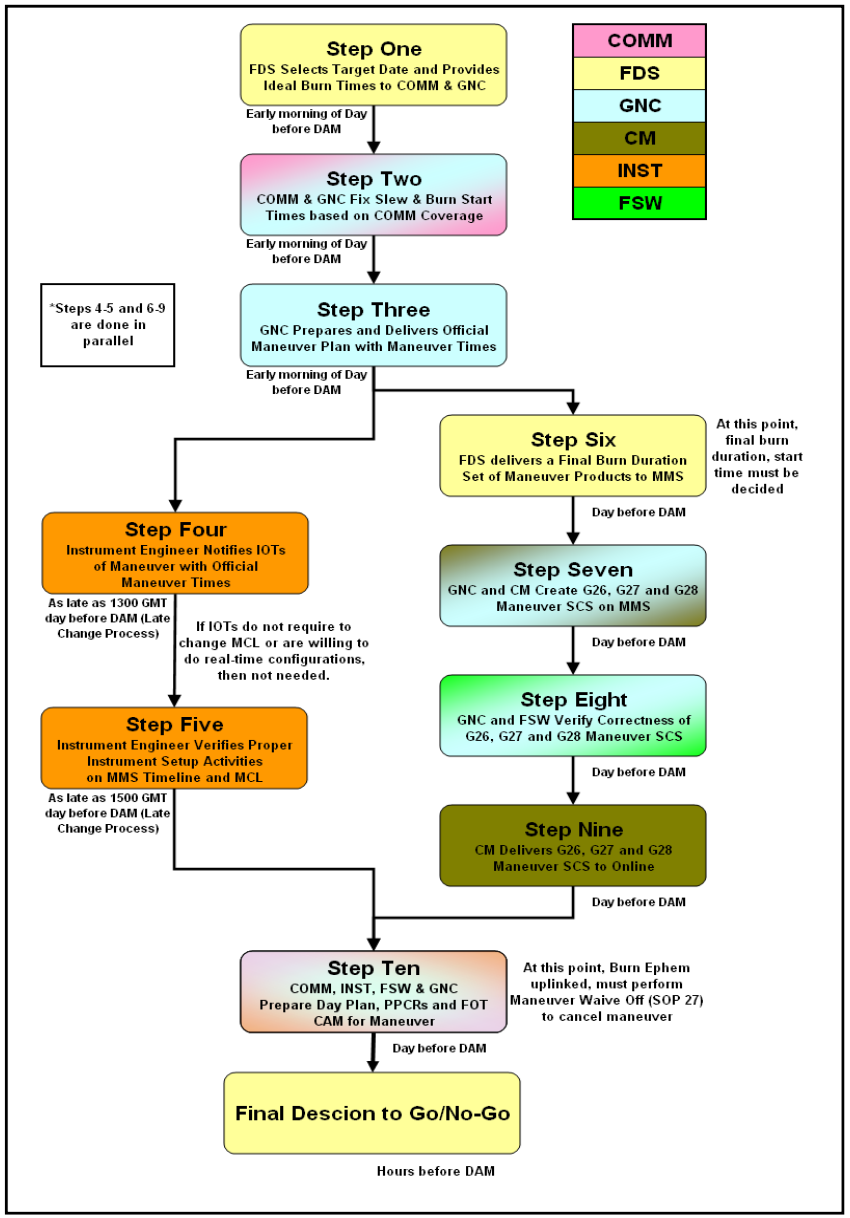
Original DMU Timing

- Process started **~2 weeks** before maneuver
- Main prep activities **~2-3 days** prior to maneuver
- **Multiple** personnel required
- **Reliant on stored commands**



Accelerated DAM Timing

- Process shortened to begin the **day before** the maneuver
- Main prep activities **1 day prior** to maneuver
- **Reduced personnel required**
- **Reliant on stored commands**



Risk Thresholds at Decision Point

ESC Maneuver Thresholds for DAM/No-DAM

	Pc Thresholds	Odds Range	Course of Action	Sample Scenarios
Green	**$<1.0e^{-5}$**	1:100,000 to 0	**No DAM**	
Yellow	**($1.0e^{-4}$-$1.0e^{-5}$)**	1:10,000 to 1:100,000	**Altered DMU/No DAM**	• **Maneuver of convenience**; Replan Nominal DMU burn time or execute DMU early • For well-tracked objects with small miss distances
Orange	**($1.0e^{-3}$-$1.0e^{-4}$)**	1:1,000 to 1:10,000	**DAM**	Solution within mission/science requirements and low uncertainties
Red	**($1.0e^{-2}$-$1.0e^{-3}$)**	1:100 to 1:1,000	**DAM**	Execute even if outside mission/science requirements
Black	**$\geq 1.0e^{-2}$**	1:100	**DAM**	**Maneuver at all costs** Even if Ongoing (Non-Maneuver Component) Anomaly or Unscreened Maneuver

- All unacceptable risks are mitigated
- Additional risks are mitigated with mission/science constraints
- Confidence in OD solution/risk accuracy must be considered as well

Information Needed to Make Decision

Info Needed for All Objects (Each Update)

- Days to TCA
- TCA
- Secondary Object Name & Catalog Number
- Primary Object Ephem Source (ASW or O/O)
- Screening Epoch
- Total Miss Distance (m)
- Miss Components (R, I, C – meters)
- Pc (single object & aggregate for mission)
  - Color coded to visual help identify risk categories
    - Red, Yellow, Green, Orange & Black
    - Thresholds for each category set by ESMO by Mission
- Indication if New Track received on Secondary
- Relative Velocity/Approach Angle
- Indication if Active Mission

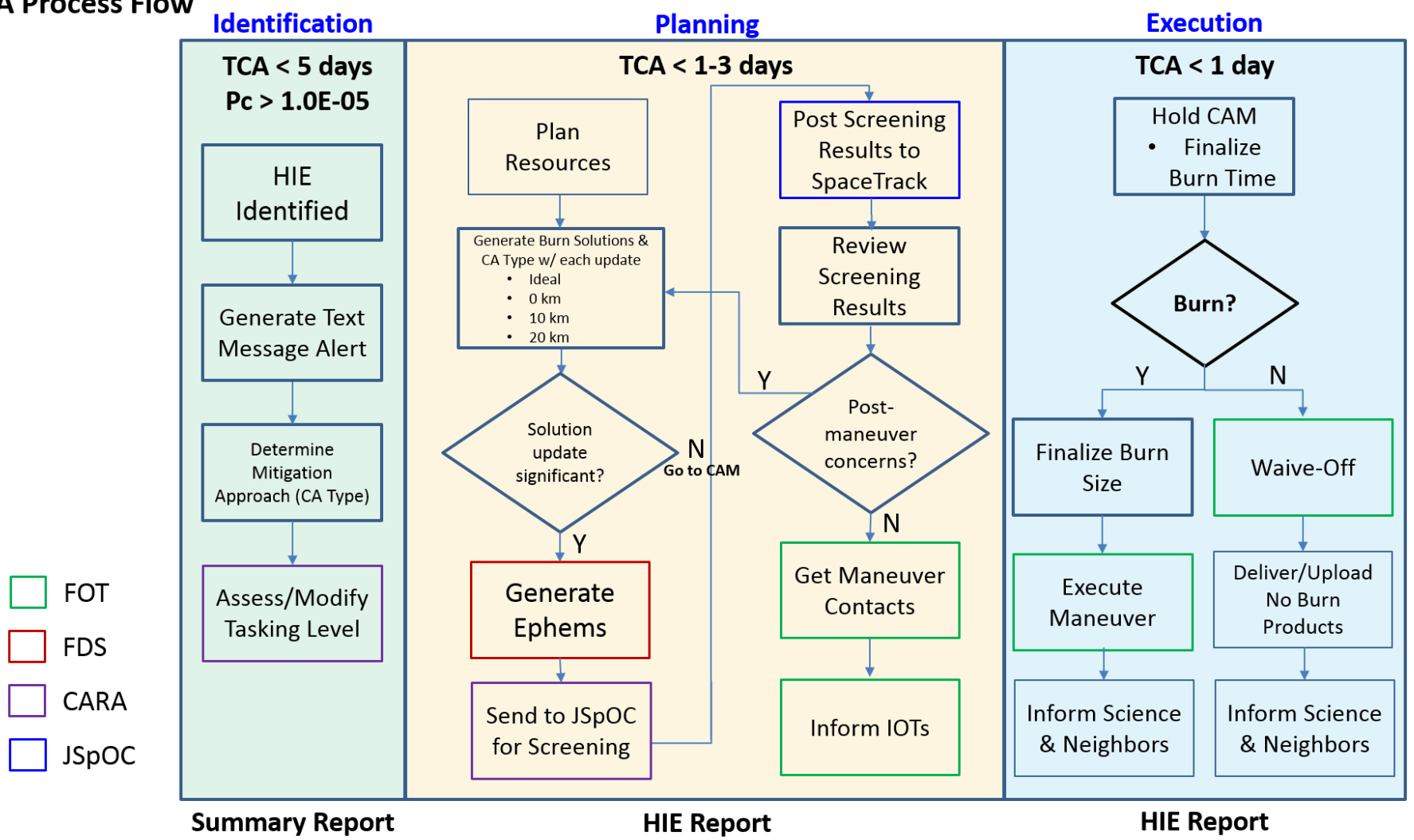
Info Needed for High Interest Objects

- Repeat of summary info for object in question (info on left)
- Plots of Total Miss History, Pc history, Component Uncertainty History
  - Indicate which data points contained a new track
- Ephem name used for O/O solution
- Event Geometry (in table form – both ASW and O/O columns)
  - Component Uncertainties
  - Relative Velocity
  - Approach Angle
- Secondary OD info
  - **Orbital Parameter** (Period, Perigee Height, Apogee Height, Inclination, EDR & RCS)
  - Avg. Observations per day
  - OD Fit Span (days)
  - Time Since Last Observation
  - Total Propagation Time (days)
  - Orbital Parameter & Event Flag Info
  - Space Weather Info
  - How well behaved is the secondary object??
- Maneuver Trade Space Plots
  - Combined, Secondary, Post-Maneuver Objects of Concern
  - Timeframe of MTS plot would be dictated by Event Type/Mitigation Approach
  - Delta-V or Burn Duration to stay within Mission/Science Control Box
- Optimized Maneuver Solution (show on plot & separate)
  - Targeted probability for maneuver solution mitigating risk

Documentation – Mission Director Handbook

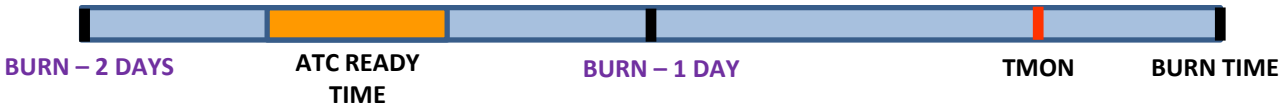
- **Reviewed Overall Process with Mission Stakeholders**
- **Documented the Overall CA Process in the Mission Director Handbook**

CA Process Flow



Maneuver Execution Enhancement

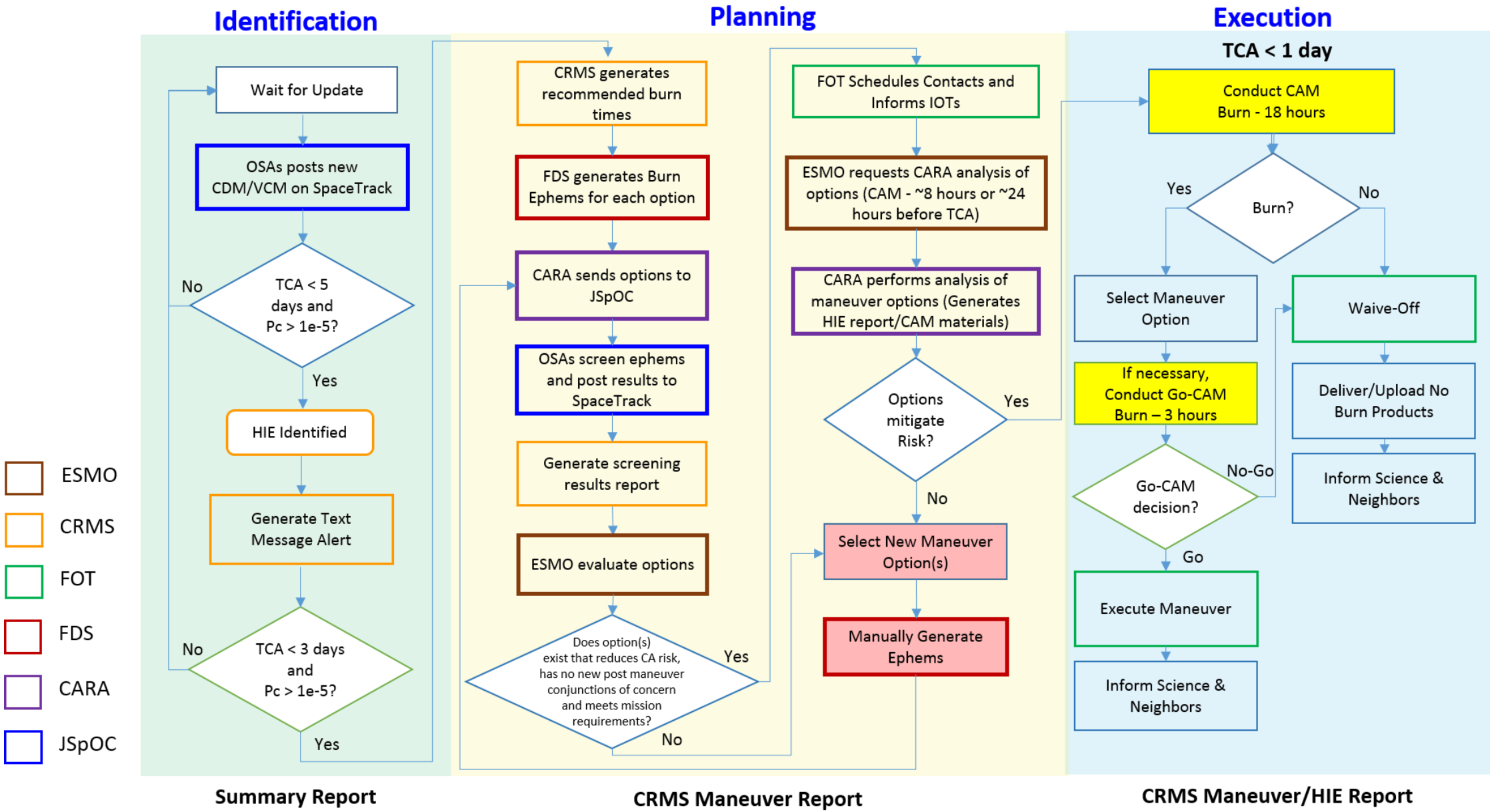
- Needed to remove reliance on Stored Commands (ATC)
- TMON/RTCS enhancement
  - Upload time of burn
  - Upload burn duration
- TMON will wait to run until time uplinked then kick-off RTCSs
- Still need to generate ephem, get it screened and evaluate results
- Timeframe and how it improved
  - ATC need by 1500-1900z day before
  - TMON patched by 4 hours prior to burn



TMON →
MASTER RTCS →

RTCS/TMON	GMT Time	To be Executed Via TMON Process on 2016 / 105	Rel CMD Timing
TMON 55	13:15:38	*TMON 55 Activation*	(DV - 1:00:01)
RTCS 30	13:15:39	*DMU Master RTCS 30 Activated*	(DV - 1:00:00)
RTCS 180	13:15:39	FS1_DISABLE_NTCH_FLT	(DV - 1:00:00)
	13:15:41	FS1_DISABLE_WSPD_CTL	0:00:02
	13:16:09	GNC_SET_IRUA_HIRATE	0:00:28
	13:16:10	GNC_SET_IRUB_HIRATE	0:00:01
	13:16:11	GNC_SET_IRUC_HIRATE	0:00:01
	13:16:29	FS1_RESET_UPD_FILT	0:00:18
RTCS 181	13:30:39	FS1_RESET_THR_PW_SUM	(DV - 0:45:00)
	13:30:40	TCS_DISABLE_TANK_H1A	0:00:01
	13:30:42	TCS_DISABLE_TANK_H2A	0:00:02
	13:30:44	FS1_DISABLE_TMONGP=17	0:00:02
	13:30:46	TCS_DISABLE_PEPC1HA	0:00:02
	13:30:48	TCS_DISABLE_PEPC3HA	0:00:02
	13:30:50	TCS_DISABLE_PMEA1_HA	0:00:02
	13:30:52	TCS_DISABLE_PMEA2_HA	0:00:02
	13:30:54	TCS_DISABLE_PRPBDUHA	0:00:02
	13:30:56	FS1_ACTIVATE_RTCS=175	0:00:02
	13:31:04	PMS_ENABLE_CAT1LBOD	0:00:08
RTCS 33	13:55:39	CEA_SET_IC_ISEQHOLD	(DV - 0:20:00)
	13:55:40	CEF_SET_IC_ISEQHOLD	0:00:01
	13:56:10	CEA_SET_IC_AZPOS_SP2	0:00:30
	13:56:11	CEF_SET_IC_AZPOS_SP2	0:00:01
	13:56:40	CEA_SET_IC_ISEQCTAM	0:00:29
	13:57:10	CEF_SET_IC_ISEQCTAM	0:00:30
	13:57:20	FS1_SET_INHIBID(18)	0:00:10
	13:57:21	FS1_SET_INHIBID(19)	0:00:01
RTCS 183	14:00:39	FS1_DISABLE_SSST1_UD	(DV - 0:15:00)
	14:00:40	FS1_DISABLE_SSST2_UD	0:00:01
	14:00:41	FS1_DISABLE_FSS_UD	0:00:01
	14:00:49	FS1_DISABLE_NTCH_FLT	0:00:08
	14:00:50	FS1_USE_NOM_ORB_RATE	0:00:01
	14:00:51	FS1_DISABLE_RWA_FF	0:00:01
	14:00:52	FS1_DISABLE_SC_FF	0:00:01
	14:00:53	FS1_DISABLE_MAGUL_FF	0:00:01
	14:00:54	FS1_DISABLE_HGA_FF	0:00:01
	14:00:55	FS1_DISABLE_WSPD_CTL	0:00:01
	14:01:09	FS1_SELECT_HGA_EPA	0:00:14
	14:01:10	FS1_ACTIVATE_RTCS=255	0:00:01
RTCS 34	14:06:39	FS1_DISABLE_DV_BIAS	(DV - 0:09:00)
	14:06:41	PMS_ENABLE_REA1LBOD	0:00:02
	14:06:43	PMS_ARM_REA1LBOD	0:00:02
	14:06:45	PMS_ARM_REA5LBOD	0:00:02
	14:08:39	FS1_SELECT_OA_MODE	0:01:54
	14:10:39	TCS_DISABLE_HCEAGROS	0:02:00
	14:10:41	TCS_DISABLE_CKTAHTA	0:00:02
	14:10:43	TCS_DISABLE_CKTBHTA	0:00:02
	14:10:45	TCS_DISABLE_CKTCHTA	0:00:02
	14:10:47	TCS_DISABLE_CKTDHTA	0:00:02
	14:10:49	TCS_DISABLE_CKTEHTA	0:00:02
RTCS 35	14:15:39	FS1_ENABLE_DV_MNVR	INPUT
	14:16:34	PMS_DISARM_REA5LBOD	0:00:55
	14:16:36	TCS_ENABLE_HCEAGROS	0:00:02
	14:16:38	TCS_ENABLE_CKTABCHTA	0:00:02
	14:16:40	TCS_ENABLE_CKTDEHTA	0:00:02
	14:16:41	FS1_ACTIVATE_RTCS=256	0:00:01
RTCS 184	15:55:39	CEF_SET_IC_ISEQCTRK	1:38:58
RTCS 185	15:55:39	CEA_SET_IC_ISEQCTRK	1:38:58

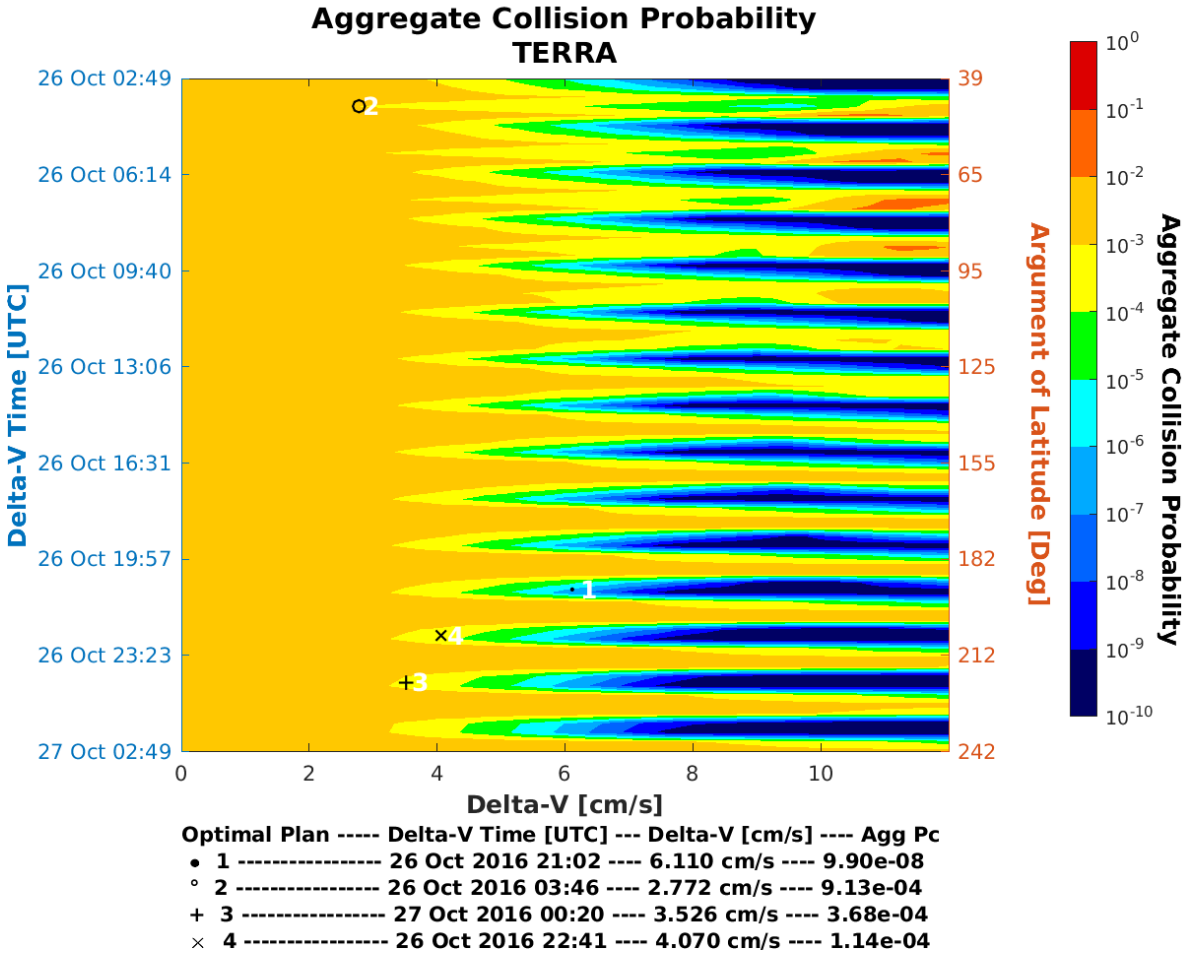
Updated ESMO CA Process Flow - 2016



Future Enhancements/Challenges

- **Enhancements**
  - **Maneuver Planning Automation**
    - Multiple Conjunction Considerations
    - Move toward Cumulative Pc versus individual object Pc
    - Working towards pre-canned maneuver avoidance plans with associated ephems built autonomously each day for all HIEs
    - Ephems would be delivered to CARA/JSpOC for screening and results would be interpreted and sent out in a report autonomously for evaluation
    - Move towards decisions & workload confined to TCA – 24 hours or less

- **Challenges**
  - **Space Fence**
    - What will order of magnitude increase looks like in terms of workload?
    - How many objects that are single station tracked?
    - Will we be able to believe data enough to make maneuver decisions on?
    - What will evaluation/decision workload look like in that environment?
  - **More collisions/debris**
  - **Post maneuver concerns shortly after burn solutions**



Questions??

BACKUP SLIDES

High Level Roles and Responsibilities

CARA Orbital Safety Analyst (OSA) @ JSpOC Responsibilities:

- Post CDM/VCMs to SpaceTrack (reg update, 1v1s or screening results)
- Perform screenings
- Perform manual OD adjustments as required
- Adjudicate tasking levels for catalog objects

NASA CARA Analyst Responsibilities:

- Investigate Conjunctions that are high risk or have space weather concerns
  - Request elevated tasking or 1v1s as appropriate
- Communicate risk to mission management
- Analyze High Risk Conjunctions & associated maneuver options (as requested)
- Develop High Interest Event (HIE) Briefings
- Support Maneuver Command Authorization Meetings (CAMs)

Space Track (Air Force managed):

- Interface to Data (requires login)

ESMO Flight Dynamics Responsibilities:

- Provides delta-v buffers
- Maneuver Planning (Generate & Deliver Ephemerides)

ESMO Collision Risk Management System (CRMS) **responsibilities** (developed by SpaceNav):

- Automated conjunction risk reduction balancing Collision Risk and Mission Requirements
  - Generate maneuver options & associated reports