# Orbital Express Mission Operations Planning and Resource Management using ASPEN

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# The Mission

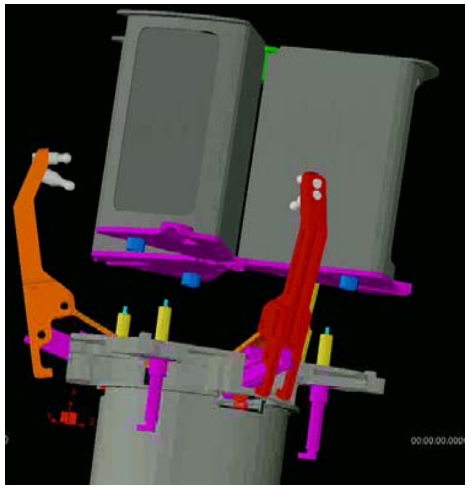
- The **Orbital Express** satellite servicing demonstrator program is a DARPA program aimed at developing
  - "a safe and cost-effective approach to autonomously service satellites in orbit".
- The system consists of:
  - the Autonomous Space Transport Robotic Operations (ASTRO) vehicle, under development by Boeing Integrated Defense Systems,
  - and a prototype modular next-generation serviceable satellite, NEXTSat, being developed by Ball Aerospace.

(source: Wikipedia)

- DARPA program
  - JPL: Russell Knight, Danny Tran, Grailing Jones, Caroline Chouinard
  - Other Participants: Boeing, Northrop Grumman, Ball Aerospace, MDA Robotics, Starsys Research, Draper Laboratories, MSFC

# Satellite Servicing Demonstration

- Navigation
- Autonomous Docking
  - Direct
  - Robotic Capture
- Transfer Propellant
- Replace Modules
  - CPU/Memory
  - Battery
- ASTRO = “Tow Truck”
- NextSat = “Out of Gas”



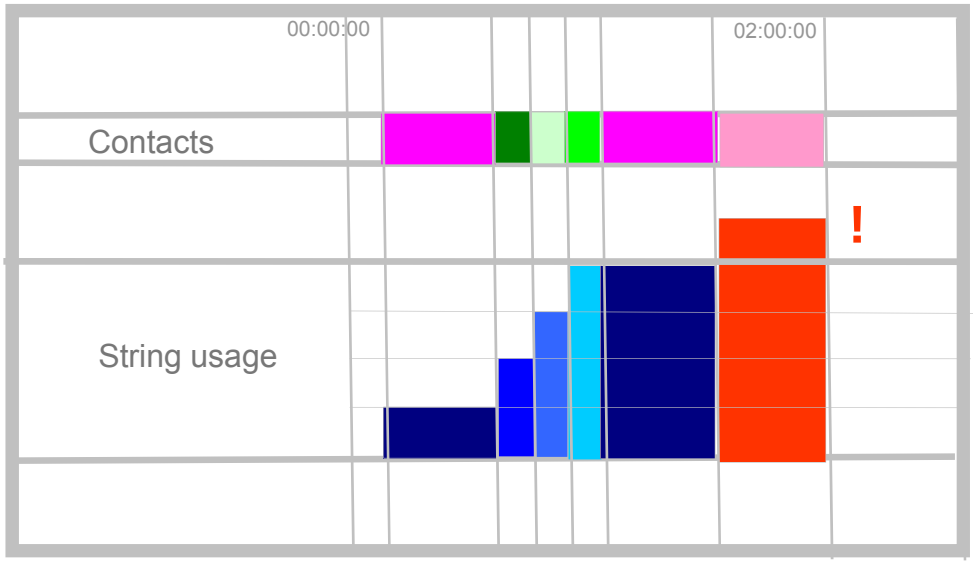
# Planning Issues of Interest

- Fast turn around of heterogeneous, dynamic plans
  - Every day is a different scenario
  - We may learn of lost passes within hours of our delivery deadline
- Operations in unknown environments, and planning to accommodate the unknowns
  - Durations of pumping, heating, cooling, transfers, and docking unknown
  - We may learn of procedure changes within hours of our delivery deadline
- Limited resources onboard
  - Energy and memory need to be managed
- Limited available communications
  - Using primarily AFSCN sites
  - TDRSS varies by the hour

# Planning Issue: The String Problem

1. A string cannot be re-used for at least 1 hour after its use.
2. AFSCN:
   - Each contact uses 1 string.
   - Contacts need at least 1 hour before the AOS of a contact to bring the string up.
3. TDRSS:
   - Up to 3 TDRSS contacts can use 1 string if the span is <= 90 min.
   - The 3 contacts do not necessarily need to occur consecutively.
   - Only the first contact (of 3) need at least 1 hour before the AOS of the contact to bring the string up.
   - All other TDRSS contacts need 1 hour before AOS to bring the string up and use 1 string.

| Contact Type: | AOS | LOS |
|---|---|---|
| TDRSS | 00:00:00 | 00:30:00 |
| AFSCN | 00:30:00 | 00:40:00 |
| AFSCN | 00:40:00 | 00:50:00 |
| AFSCN | 00:50:00 | 01:00:00 |
| TDRSS | 01:00:00 | 01:30:00 |
| TDRSS | 01:30:00 | 02:00:00 |

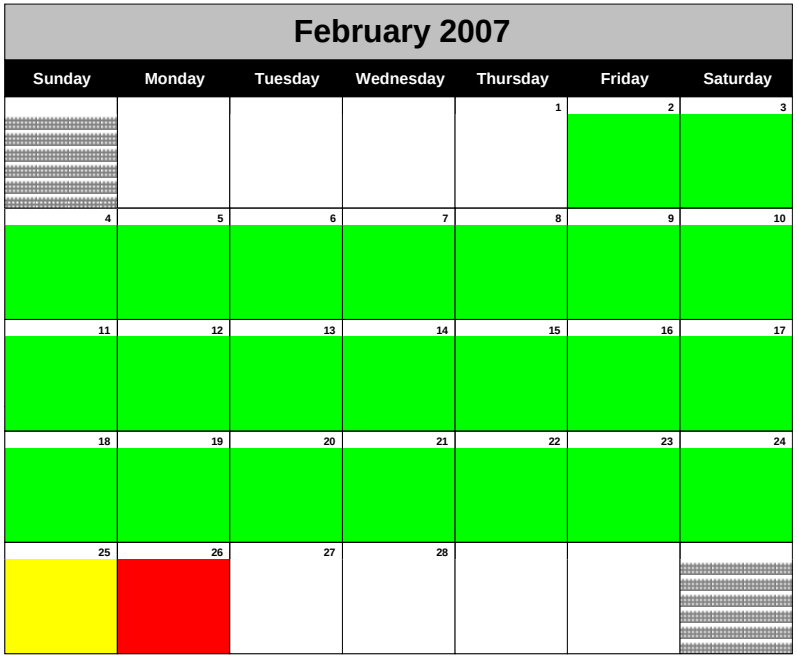


# JPL Contribution

- Automated Mission Planning for ASTRO:
  - Use ASPEN (Activity Scheduling and Planning ENvironment)
    - ASPEN requested by Boeing
    - Reasons about states, resources, activity timing
    - User interface that satisfied ASTRO planning use cases
    - Adaptable for use with MS SQL Server (added for Orbital Express)
  - Provide SRP staffing
- Automated Mission Planning for NEXTSat:
  - Decided to add planning for NEXTSat during rehearsals
  - Used ASPEN objectives
  - Satisfied simple set of rules
    - Number and type of contacts per day
    - Listed the command names
  - No procedure models: modeling limited to automating objectives

# Planning Flow

- Long-term planning ■
  - 24-7 days out from execution day
  - Scenario Planning
    - Decide on the day for each scenario
    - Might interact with Trajectory Planning
  - Trajectory Planning
    - Decide on actual spacecraft trajectory, illumination, and site visibilities
  - Resource Planning
    - Approx. file information, contact times
    - Assign TDRSS and AFSCN resources to scenario
    - Project memory and energy envelopes




- Daily planning ■
  - 1 day out from execution day
  - For aligning with actual telemetry and actual data products
  - Trajectory Planning
    - Project accurate spacecraft trajectory, illumination, and site visibilities
  - Resource Planning
    - Need precise file information, exact contact times
    - Align TDRSS and AFSCN resources to match contact times
    - Project memory and energy envelopes, repair if necessary
    - Respond to lost/gained contacts, changes in procedures, changes in the daily plan
  - Scenario Planning
    - Verify that the plan matches expectation

# Planning Flow

**Long-Term** (24-7 days out from execution day)

- *Scenario Planning*
  - Decide on the day for each scenario
  - Might interact with Trajectory Planning
- *Trajectory Planning*
  - Decide on actual spacecraft trajectory, illumination, and site visibilities
- *Resource Planning*
  - Approx. file information, contact times
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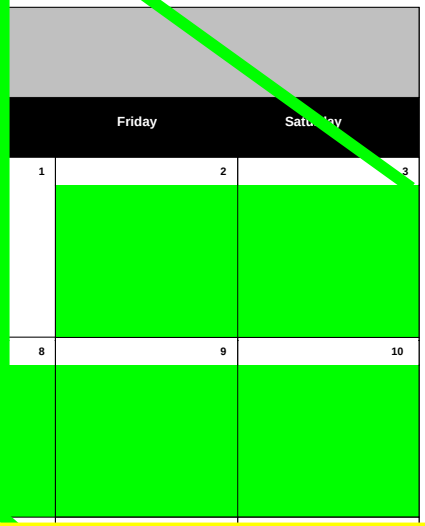
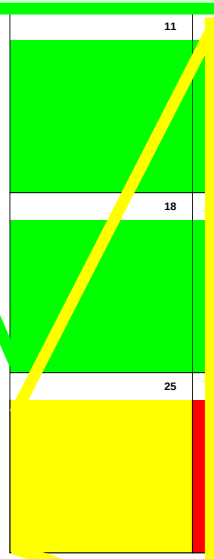


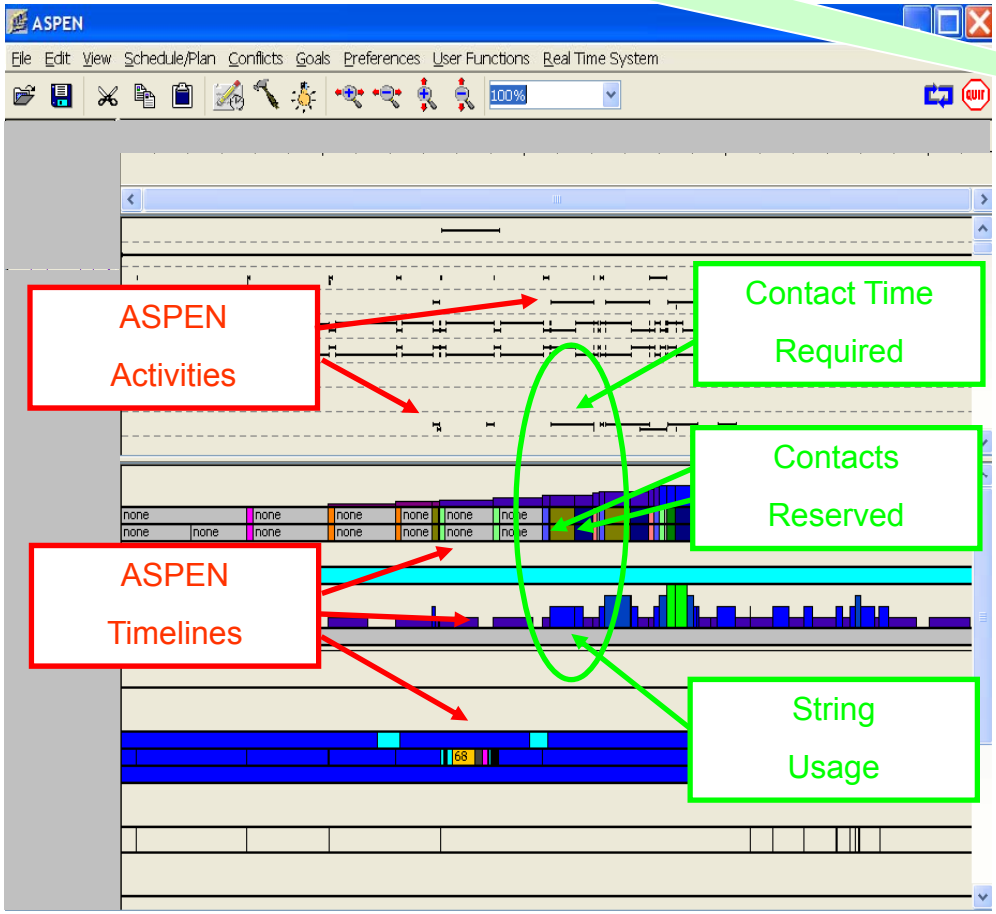



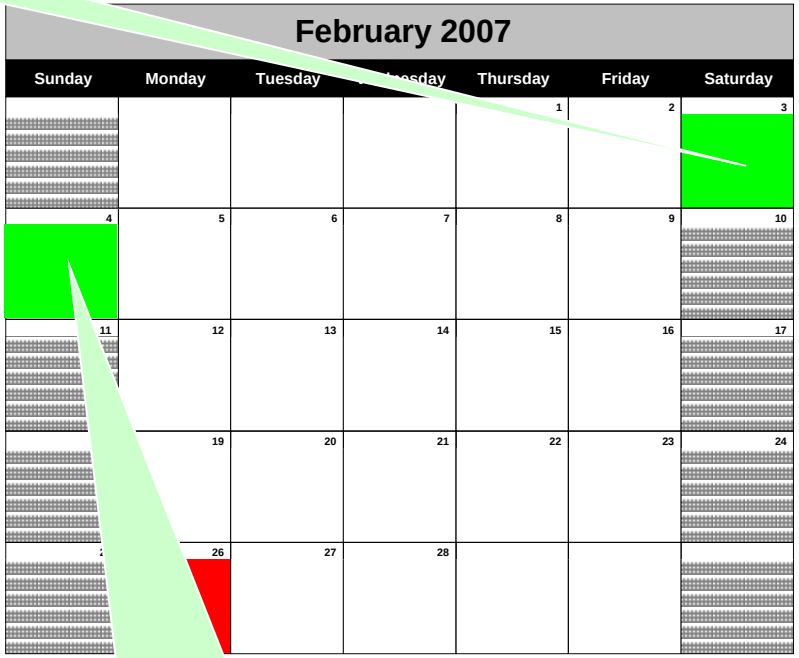

**Daily** (1 day out from execution day)

- *Scenario Planning*
  - Verify that the plan matches expectation
- *Trajectory Planning*
  - Project accurate ST, illumination, and site visibilities
- *Resource Planning*
  - Precise file information, exact contact times
  - Align TDRSS and AFSCN resources to match contact times
  - Project memory and energy envelopes, repair.
  - Respond to lost/gained contacts, changes in procedures, changes in the daily plan

# Life of a plan

**1. Decide on scenario to execute, e.g., mated fluid transfer, "family portrait"**



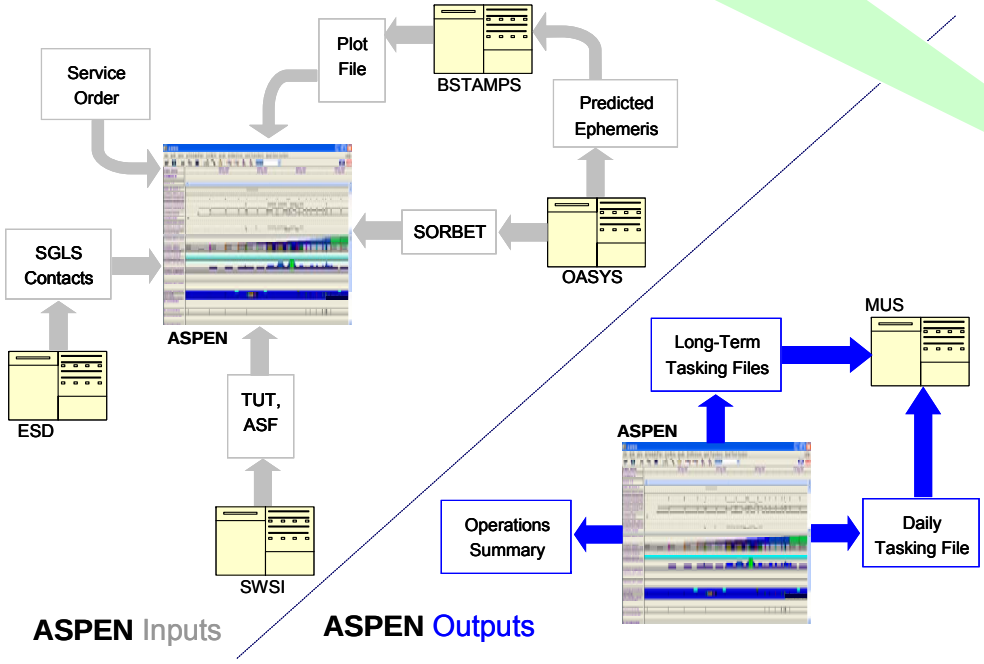



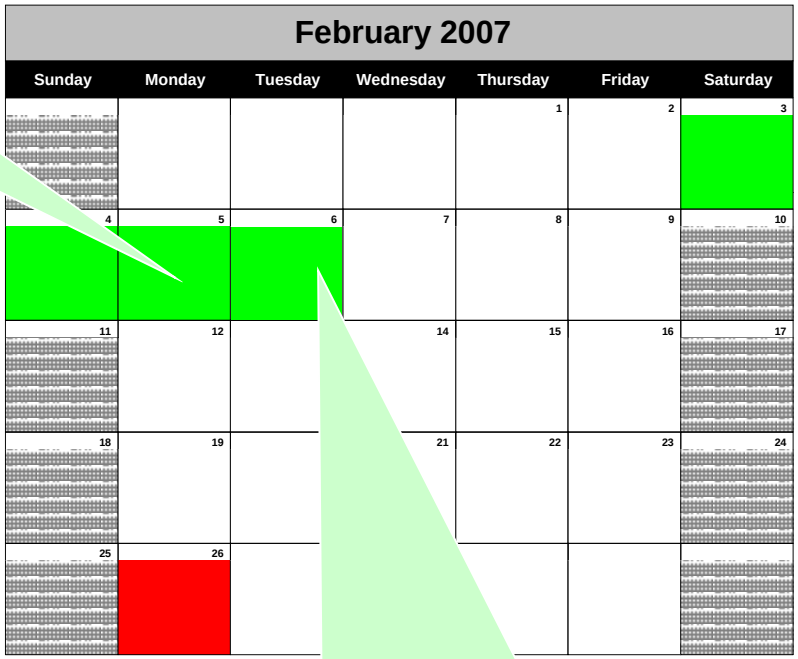

**2. Generate the trajectory products**

# Life of a plan

**-22 Days: Generate the complete resource plan**

**Generate the execution scripts for onboard the spacecraft**



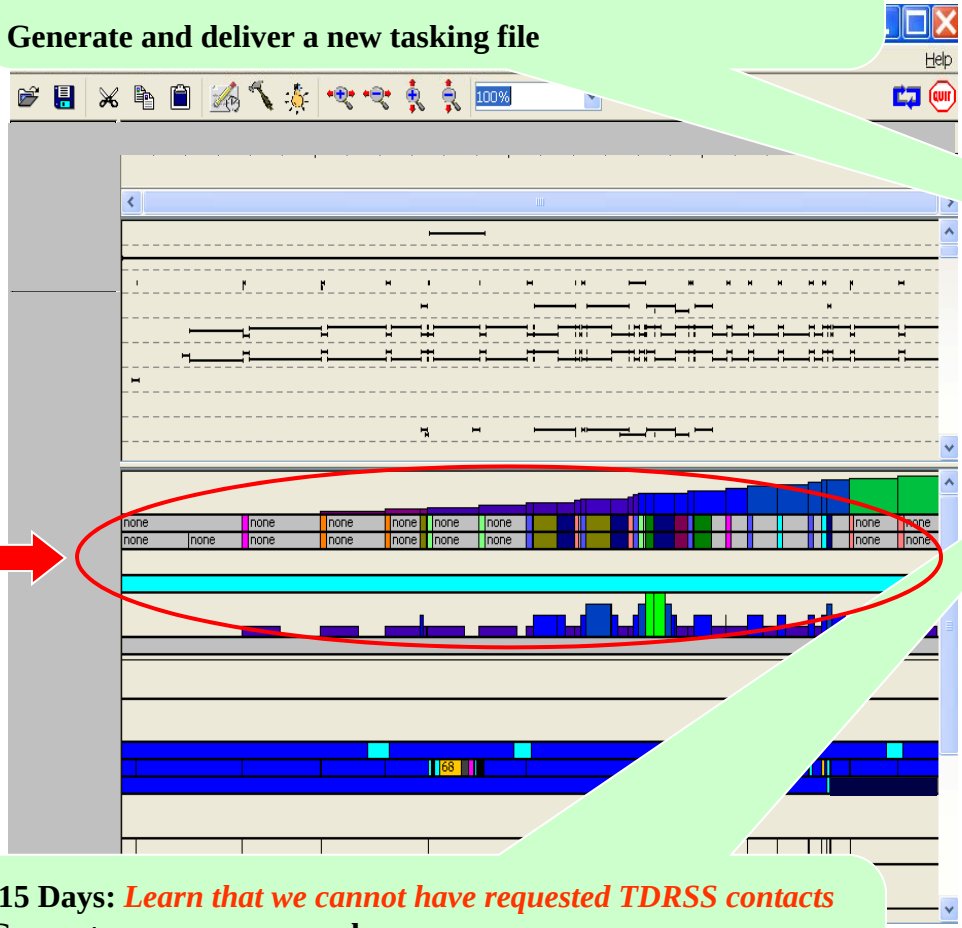



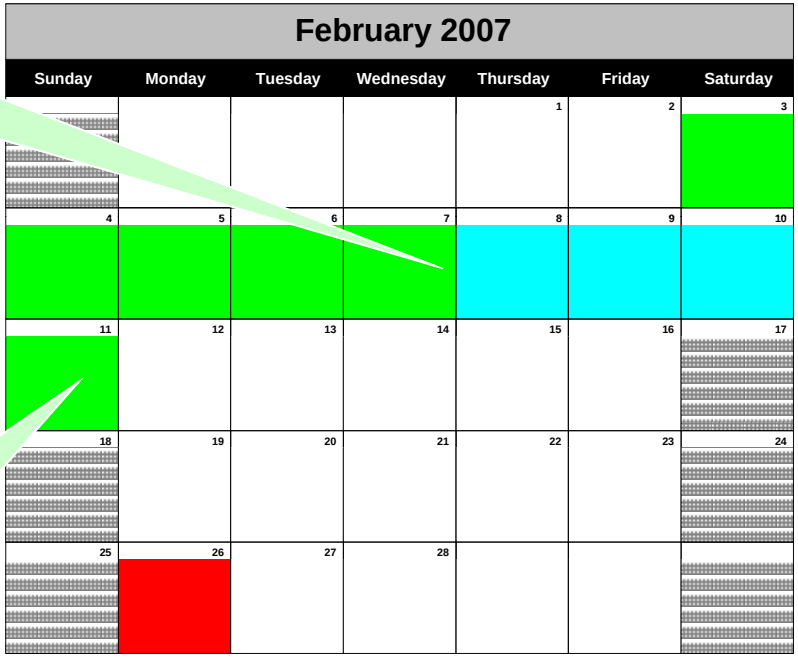

**-21 Days: Generate and deliver to the Air Force the "tasking file" (complete, executable plan)**

# Life of a plan

**-20 Days:** ***Learn that we cannot have requested AFSCN contacts***
**Generate a new resource plan**

**Generate and deliver a new tasking file**




■ : No Changes to Planning

**-15 Days:** ***Learn that we cannot have requested TDRSS contacts***
**Generate a new resource plan**

**Generate and deliver a new tasking file**

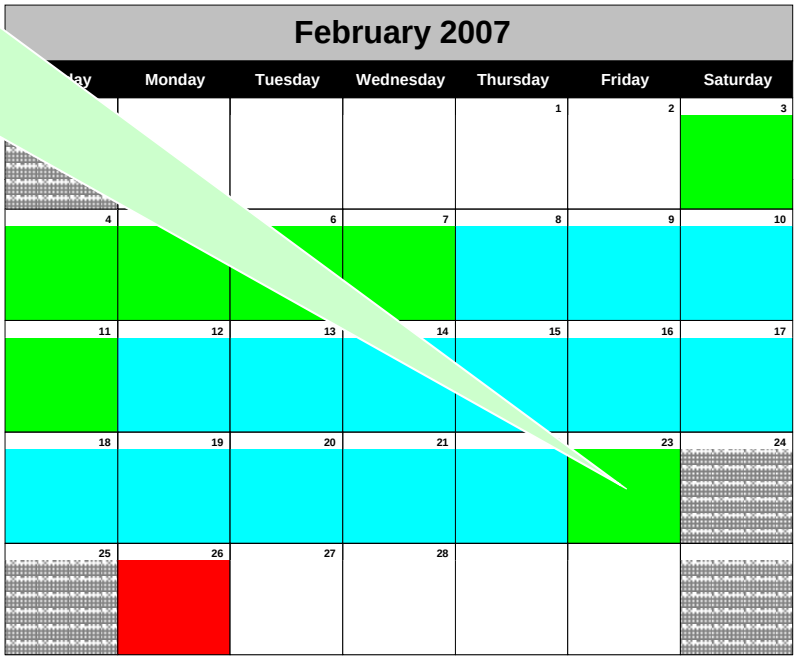
# Life of a plan

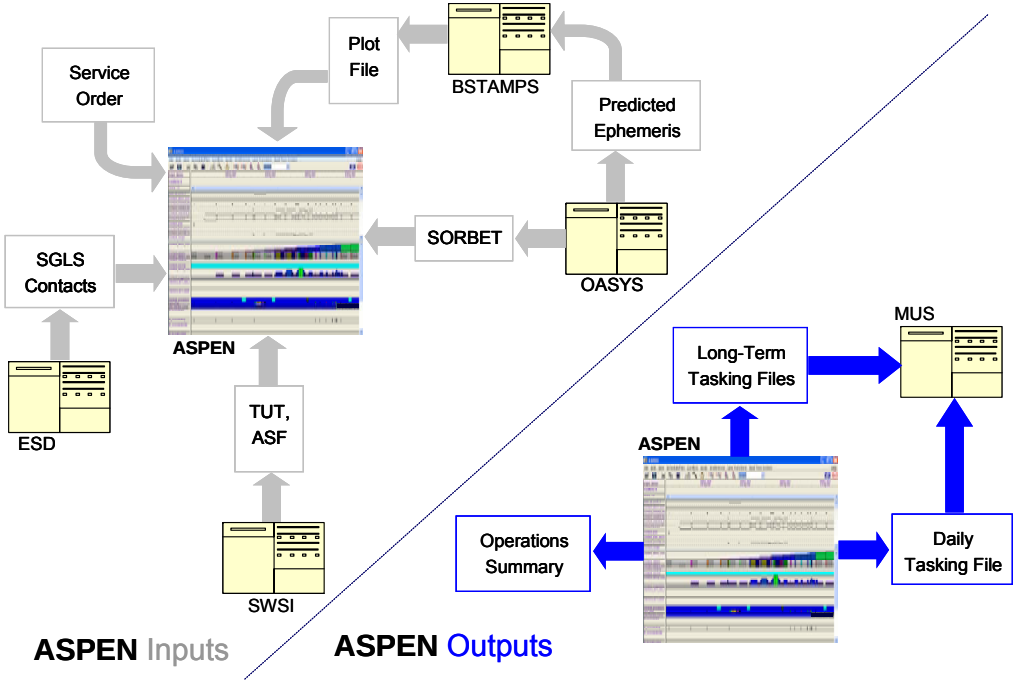
**-3 Days:** ***Learn that the fluid transfer procedure has changed***
**Regenerate the ASPEN model that represents the procedure**

**Regenerate a complete resource plan**

**Regenerate and deliver a new tasking file**

**Regenerate the execution scripts for onboard the spacecraft**



# Life of a plan

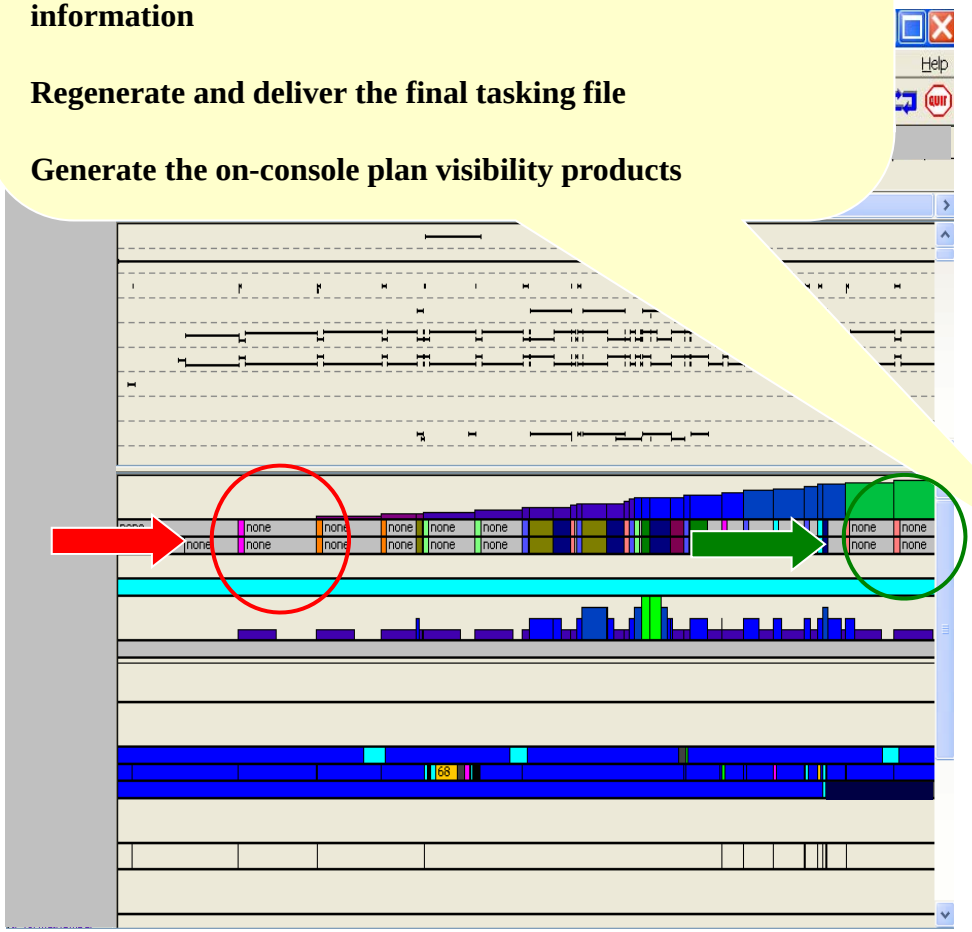
**-1 Day:** ***Learn that we are losing 2 AFSCN contacts, but that we are gaining 1 long AFSCN contact later in the day***
**Regenerate a complete resource plan, if possible**

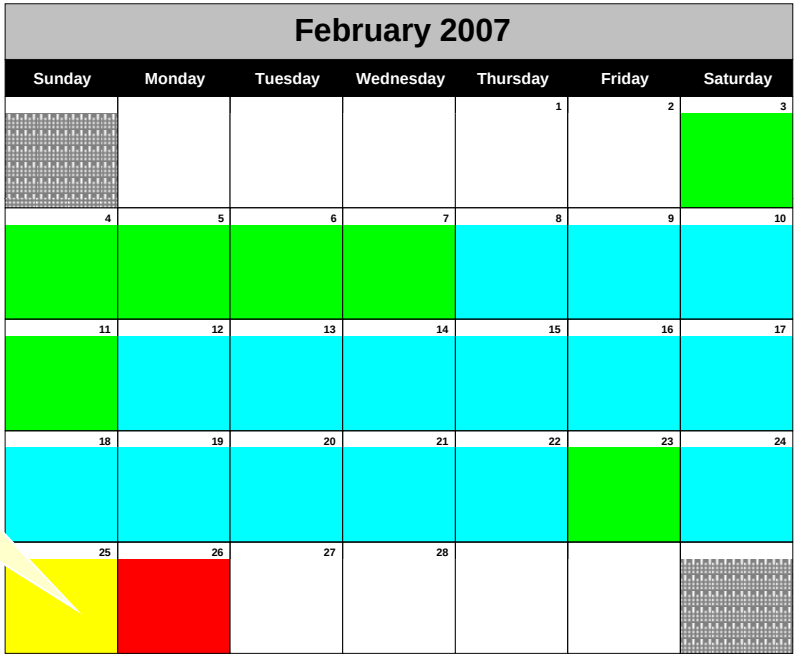
**Produce the required files for uplink**

**Regenerate a complete resource plan with the new file information**

**Regenerate and deliver the final tasking file**

**Generate the on-console plan visibility products**



# Life of a plan

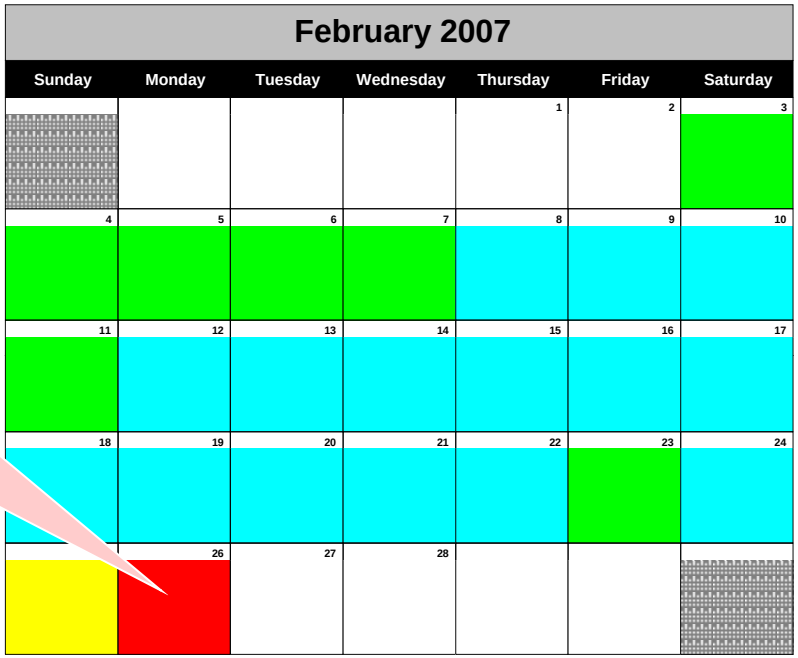
**-0 Days: The plan is executed on the ground**

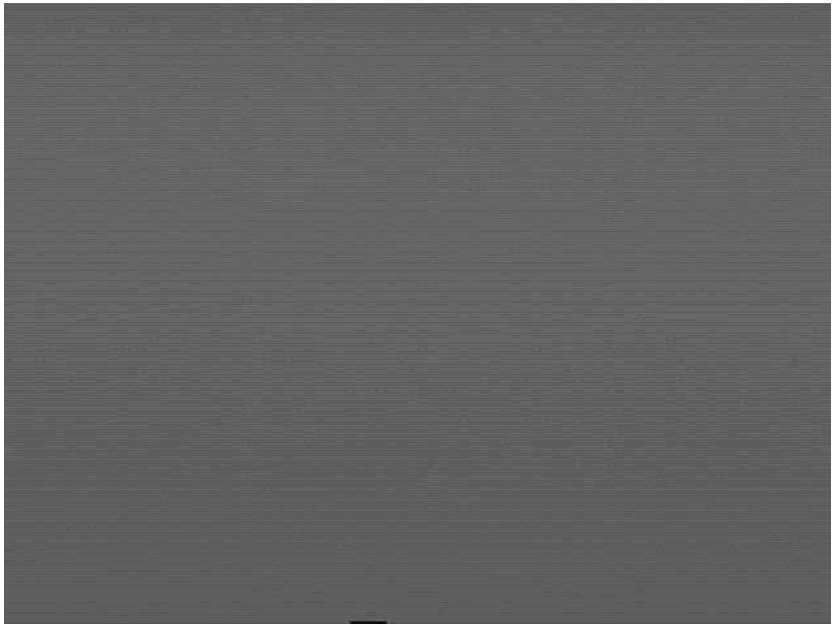
**The tasking file is executed by Air Force personnel**

**The stored resource plan is executed by the telemetry system**

**The on-console clock product is executed by the clock program**

**The on-console plan is displayed via a read-only planning GUI**



4/17/07 Video (a composite of still pictures) shows NextSat held by the robotic arm and moved into berthing position. The robotic arm releases NextSat, which is then grabbed by the ASTRO capture mechanism and pulled into a mated position.

# Related and Future Work

OE (Related Work):

- 1997: a docking of a Progress supply ship at the Mir space station was attempted but did not succeed.
- 2003: AFRL launched XSS-10
- 2005: XSS-11, with the objectives of advancing autonomous navigation and maneuvering technologies.
- Other missions approaching the idea of autonomous satellite servicing with rendezvous and other robotic maneuvers:
  + NASA's DART satellite
  + Japan's Nasda Engineering Test Satellite 7

# Related and Future Work (cont.)

ASPEN (Related and Future Work):

- MER mission planning is aided by the NASA Ames Research Center software tool MAPGEN.
- ASPEN has been successfully used as a ground planning system for earth-orbiting missions on both Orbital Express, EO-1 (on-going), and MAMM.
- Continuous Activity Scheduling Planning Execution and Re-planning (CASPER)
    + Continuous cycle of decision-making capabilities for real-time scheduling, repair and optimization
    + Rovers, aerial vehicles (aero-bots) and for surface and under-water vessels.
- ASPEN is being researched and used as a tool to schedule DSN.
- Automating satellite operations is being considered for the DESDynI project using an ASPEN hybrid

# Conclusions

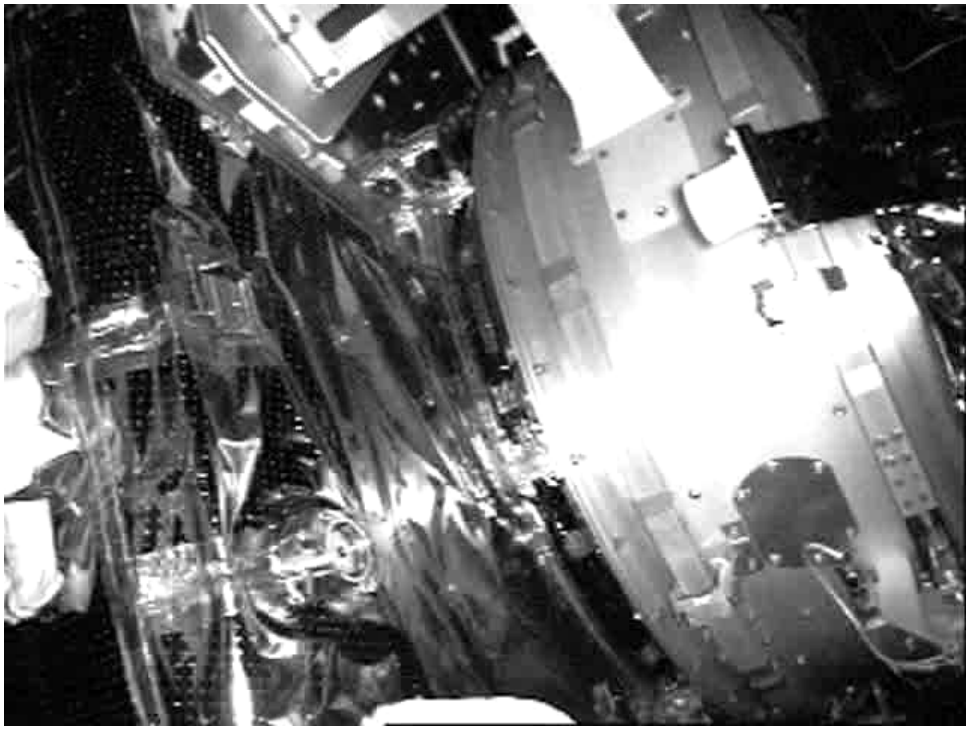
- Flexibility of ASPEN
  - Accommodate changes to procedures
  - Accommodate changes to daily losses and gains
  - Responsive re-planning
  - Critical to success of mission planning
- Auto-Generation of activity models
  - Created plans quickly
  - Repetition/Re-use of models each day
  - Guarantees the AML syntax
- One SRP per day vs. Tactical team

# Acknowledgement

The research described in this presentation was carried out by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the Defense Advanced Research Projects Agency.

# Backup Movies

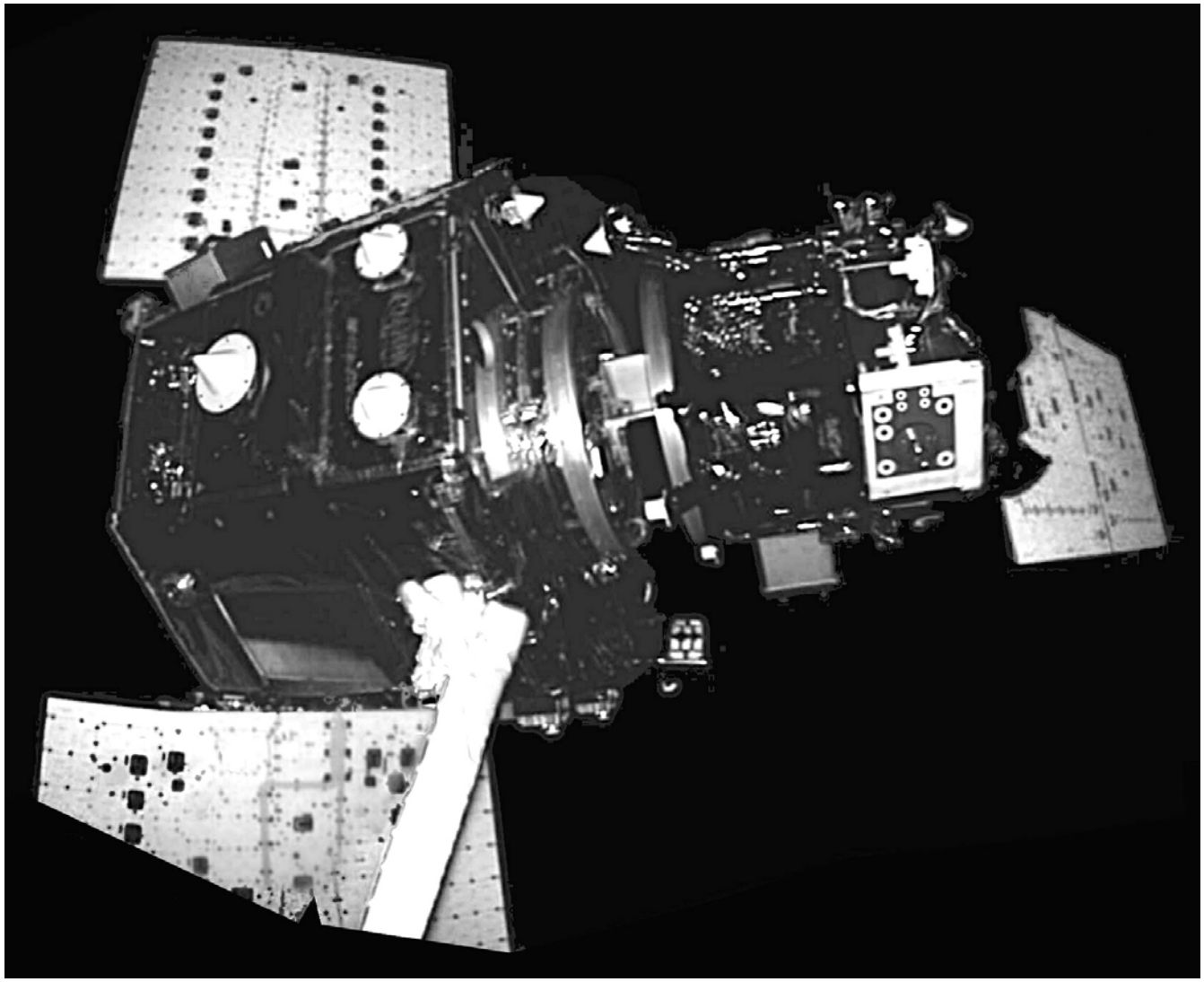
3/28/07 Global mated survey of the two spacecraft by the arm camera. The video was created from 1,600 still pictures taken by the camera.



4/17/07 ASTRO and NextSat today separated for the first time, and the launch ring between them was safely ejected. The video of the separation is a composite of still pictures, and shows NextSat separating from the launch ring and then the robotic arm closes in on the satellite and grapples it. The ring eject video is also a composite of still pictures.

# Image

“Family portrait” picture of both the ASTRO and NextSat, taken from the robotic arm during the 4 km separation demonstration conducted June 22. (This is the only on-orbit picture that includes the ASTRO since the NextSat does not have any cameras.)



# More Movies

On-orbit video of scenario 5 (conducted June 16). The jumps in the video are due to that fact that it is made up of a composite of still pictures; the video runs faster than real-time.