The Success of the Deep Impact Mission

A Study of Risk Management Processes

Rick Grammier - Project Manager

Agenda

- State of the Project one year prior to launch
- Contributing causes for this state
- Solutions implemented
- Risk Management in context of solutions
- State of the Project at Launch
- Managing the risks for Encounter
- Summary

State of the Project One Year Prior to Launch (January 2004)

- Already had delayed launch one year (very unusual for a planetary launch)
- Had not completed development of the flight avionics hardware or software
- System level verification and validation program not started
- Fractured team and split responsibilities
- Science instruments completed and delivered
- Serious financial overruns - - NASA HQ on the verge of canceling the program

Contributing Causes for State of Affairs

- Rigorous engineering processes either not understood or not followed
  - Cultural differences between JPL and System Contractor
  - Knowledge and experience gaps within the team
  - Independent check and balance process eviscerated
- Reporting process did not provide a clear, overall picture
  - What are the primary issues and threats?
  - What are the plans and approaches for dealing with them?
  - What trends are being seen and what do they mean for the future?
- Ineffective Reviews Process
  - Only going through the motions, no real review rigor and penetration
  - Lack of rigorous follow-up and closure of issues uncovered
- Disorganized and ineffective teaming arrangements
  - Who has product responsibility at each level and at each life cycle phase?
  - Organization with the responsibility didn't necessarily have the knowledge or skills to deliver the product
  - Lack of effective management and leadership at multiple levels

Contributing Causes for State of Affairs - 2

- Lack of understanding and capability to conduct a flight system Validation and Verification (V&V) program
  - Two key V&V processes not implemented
  - Lack of understanding the "Verification" part of V&V
  - Need for very high fidelity test beds
  - No appreciation for data reduction and analysis needs
  - Late system maturation impeded scenario development and test
- Inadequate Flight Operations Concept and Plan
  - Lack of sufficient early staffing and funds
  - Very green team
  - Originally, the system contractor had responsibility
    - Significant experience and cultural mismatch
  - No appreciation for true impact of 1 year launch delay and only 6 months of operations

Solutions - Rigorous Engineering Processes

- JPL's Flight Project Practices and Design Principles
  - Team/Project had previously reviewed, but in piecemeal fashion
    - Lack of understanding in context of Deep Impact implementation
    - The **real value is in the discussion** of whether each requirement is met or not
  - Held several working meetings to go over each requirement
  - Exceptions are OK, but always **understand the risk** of each exception and the rationale as to why that risk is acceptable
    - New risks captured and tracked in the Project's Risk List
- Re-established Mission Assurance rigor
  - Formed a Mission Assurance Audit Team to determine state of affairs and make recommendations
  - Subsequently formed Tiger Team of experts to implement recommendations and correct deficiencies
  - It was painful and costly, but - - - **you have to do the right thing, right**

Solutions - Reporting Process

- Standard Monthly Management Review process was neither sufficient or penetrating
- Created new **weekly** reporting process
  - Inputs and issues from each lower unit (subsystem level), system engineering level, and intermediate management levels
  - Reporting by each lower unit lead - - - "get it from the horse's mouth and ask your questions"
  - Highly metrics driven and reported metrics change with the work phase
  - Included a coherent list of work to go at the unit level and progress indicators - - - aka, the "punch list"
  - Assign action items and follow up on them the very next week
  - Identify new risks for the risk list
- All areas participated!
  - Engineering team, business team, science team, management team

Solutions - Review Process

- Followed the detailed review guidelines that contain scope and content for each required review
  - No more "winging it"
  - It's a lot of work, but if you are going to do it, do it right
- Ensured the independent review board membership and makeup was appropriate for the review being conducted
- Allocated sufficient preparation time and kept it in front of everyone
  - Don't succumb to the inevitable whining about being too busy with day-to-day issues
- At the conclusion of the review:
  - Ensured all issues were captured in writing and understood
  - Ensured each issue had associated action(s), assignee, and due date
  - Checked status weekly to ensure actions rapidly resolved
- For final issue closure, closed the loop with the review board member who generated the issue or action

Solutions - Teaming Arrangements

- Replaced most of the 1st and 2nd tier management team
- Organized product teams to take advantage of flight project experience and specific product knowledge
  - Combined membership from JPL and contractor
  - Only one person ultimately responsible for each subsystem
- Provided continuous management and engineering presence at the contractor site
  - Improved communications, continuous interaction
  - Quickly identify and resolve problems
  - Knowledge transfer
- Hands-on, day-to-day management by the Project Manager and Deputy Project Manager
- Weekly status review meeting served to keep team focused and everyone on the same page

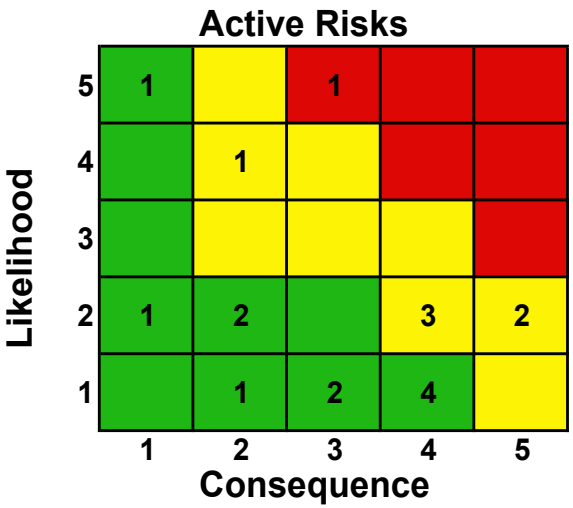
Solutions - Flight System V&V Process

- Implemented "Test as fly and fly as you test" philosophy and process to define test program and content at the system level
  - If you test it this way, then fly it that way. If you are going to fly it in a certain way, then test it that way
  - Exceptions are inevitable, but why are the exceptions OK and how can the risk be mitigated?
  - Similar to Flight Project Practices and Design Principles Process
- Defined and generated an Incompressible Test List
  - Recognizing unforgiving launch and encounter windows, this list defined the tests that must be completed prior to launch or prior to encounter
  - Completion means **all** data analyzed and **all** issues resolved, fixed, and re-tested
  - Provided priorities and focus on what needed to be done
  - Expended significant effort on increasing test bed fidelity and validating test bed models
- Additional staff brought on to define and implement the data reduction and analysis capability

Solutions - Effective Risk Management

- Established simple but effective Risk Management Process
  - Generated spreadsheet based Risk List - - a living document
  - Active, Accepted and Retired risks
  - Review risks frequently, assign actions and follow-up on those actions
  - All project areas attend these Risk List reviews
  - Assign risk rating to each risk and change as the risk is mitigated or worsens
  - The value of the rating process is in the discussion it engenders and the tremendous increase in understanding/characterization of the risk

"Rigor, penetration, and follow-up"

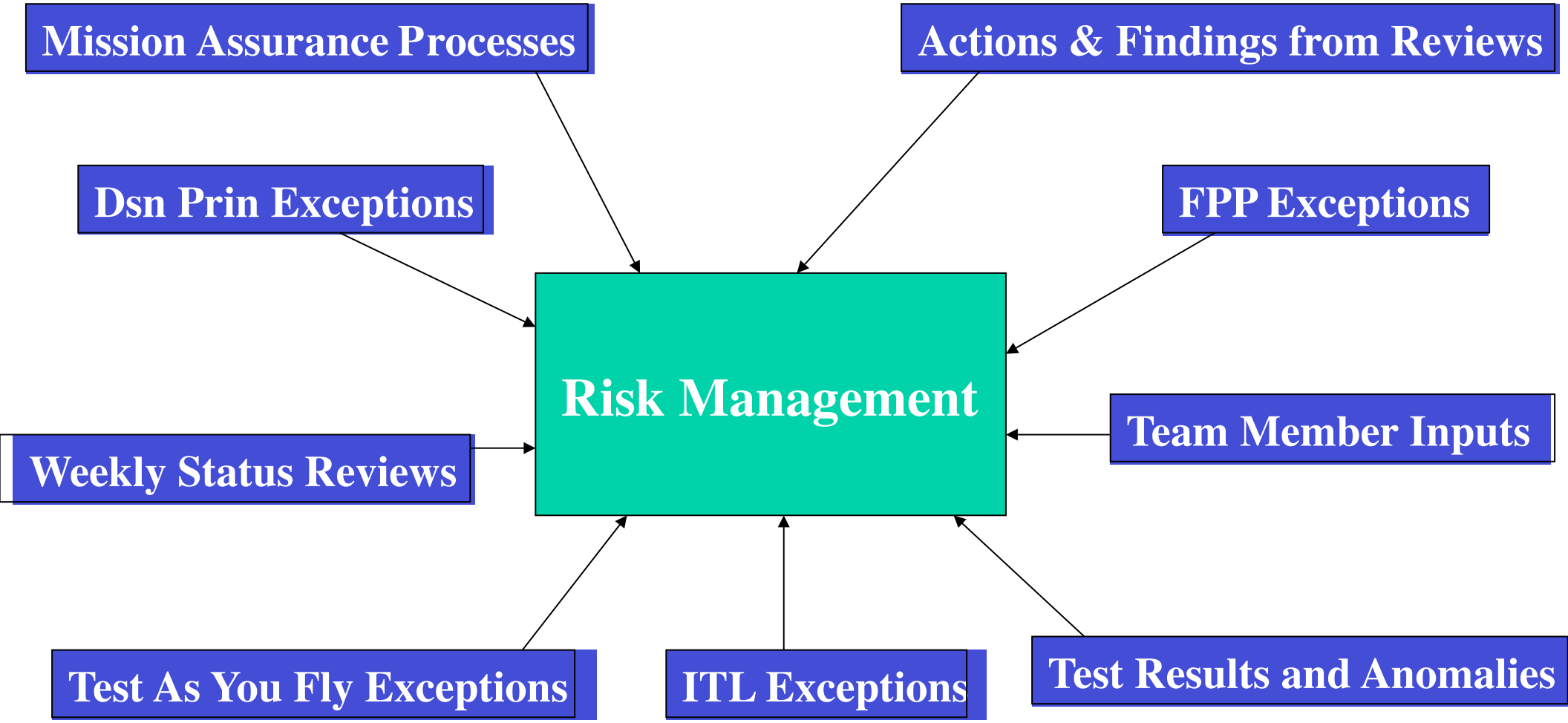


Likelihood	
1	Very low - Very unlikely
2	Low - Unlikely
3	Moderate - Significant likelihood
4	High - More likely than not
5	Very high - Almost certain

Consequence	
1	Minimal or no impact to mission
2	Small reduction in mission return
3	Cannot meet full mission success
4	Cannot meet minimum mission success
5	Mission catastrophic - no data returned

Solutions - Effective Risk Management

- All solutions and processes feed the Risk Management Process



Solutions - Effective Risk Management

- Conducted several, in-depth, risk reviews
  - Risk Review for each mission phase (five)
  - Two Project level risk reviews pre-launch
  - Three Project level risk reviews for encounter

State of Project at Launch

- Encounter related ITL not completed
  - Particularly faulted encounter tests
- Several open issues related to encounter design
- Encounter contingency plans not identified, developed or tested
- Still had test bed fidelity issues to resolve for encounter testing
- Operations team certified/trained, but still green
- Practically every day of 6 month journey to Tempel 1 required spacecraft and test bed activity
- Low risk posture for launch and initial checkout
- Medium to high risk posture for "cruise" and encounter

⇒ Significant engineering, development and test of encounter software, sequences and fault protection still required

⇒ Too much work remaining for current size of operations team

Solutions (Post Launch)

- Retained majority of development team remaining at launch
- Retained processes used so successfully to get to launch
  - Weekly status report, punch lists, risk reviews, etc.
- Formed Encounter Working Group (EWG) to complete development and V&V of encounter
  - Firewall between EWG and daily spacecraft operations team
  - Activity led by deputy PM
  - Formed an Encounter Red Team to follow and challenge the Project regarding encounter design and verification
- Pretty much 24/7 operation after launch

Encounter Risk Management

- Accurate tracking and closure of all encounter related open items at time of launch
- 3 sigma and 6 sigma testing of encounter sequences
  - Understand what parameters we were most sensitive to
- Generation of encounter decision tree
- Identification of required encounter contingencies
  - Generation and V&V of same
- Conducted several encounter operational readiness tests (ORTs), under both nominal and faulted conditions
- Incorporated changes due to in-flight behavior
  - High Resolution Instrument (HRI) de-focus
  - Star tracker performance
- In flight tests to reduce “first time in flight” items
- Conducted three encounter risk reviews with the Red Team and senior management
- As time started to run out, concentrated more on testing nominal encounter vs. faulted encounter

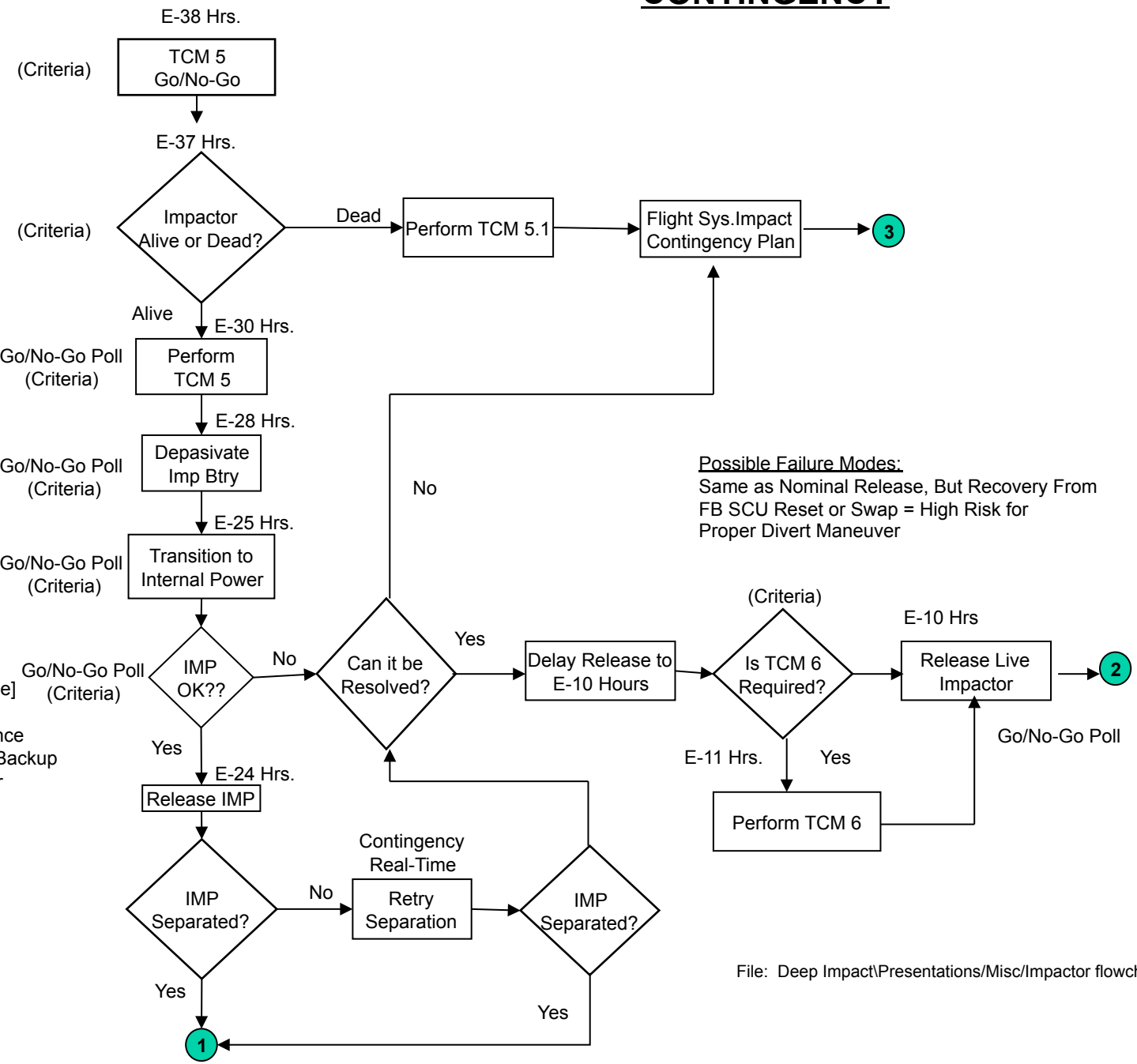
Encounter Decision Tree

NOMINAL

CONTINGENCY

1) Imp = Single String
2) Complete Imp Check-out At E-9 Days And Leave On
3) Any Failure Except S-band = Dead Impactor
4) Probability @ This Point = Negligible

1) Probability of Imp Failure Due to TCM-5 = Negligible
2) Going to Impactor Internal Power = Most Likely Failure at this Point (1st in Flight) → Probability = Low to Negligible



Possible Failure Modes:
Same as Nominal Release, But Recovery From FB SCU Reset or Swap = High Risk for Proper Divert Maneuver

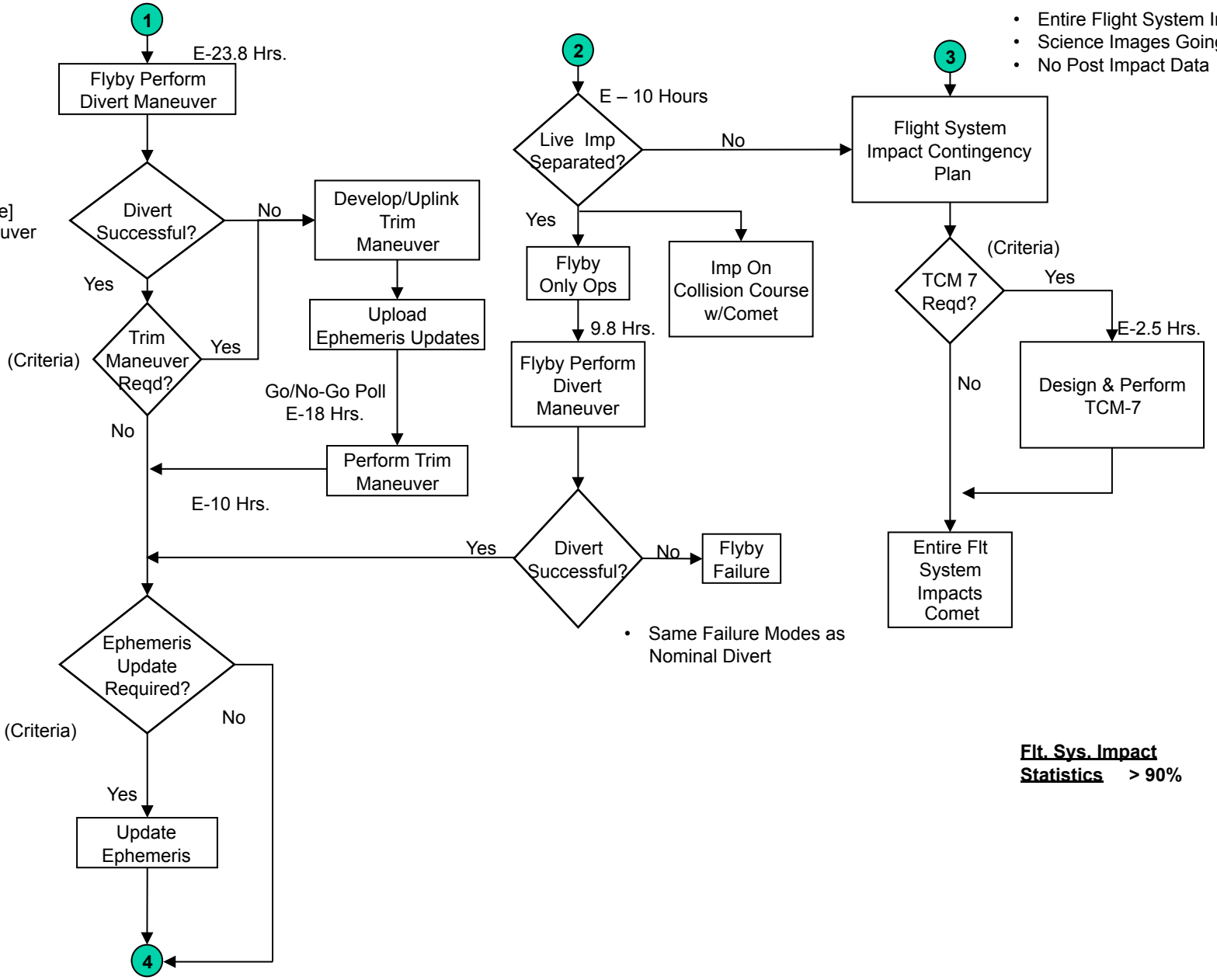
Possible Failure Modes:
Failed Electrical Separation (1st in Flt.) [Low]
Failed Mechanical Separation (1st in Flt) [Low]
Failed Thrusters Post-Sep. (1st in Flt.) [Low to Negligible]
SCU Reset @ Separation (Flyby or Imp) [Low]
- ↳ Imp = FP Recovers & Resumes Critical Sequence
- ↳ FB = FP Recovers on Same Side or Swaps to Backup if HW Failure = Possible Failed Divert ⇒ Larger Divert Trim Maneuver (i.e., Recoverable)

File: Deep Impact\Presentations/Misc/Impactor flowchart 3-0

Encounter Decision Tree

NOMINAL

CONTINGENCY



- Entire Flight System Impact
- Science Images Going In
- No Post Impact Data

Possible Failure Modes:

- HW Fault Causes FP to Interrupt Burn, Recover & Resume [Negligible] This is Recoverable with Trim Maneuver
- SW or Sequence Error Results in Under Burn or Over Burn [Low]

- Same Failure Modes as Nominal Divert

Nominal Impact Statistics
Miss - 0.067%
Dark - 0.10%
Lit Impact - 99.83%

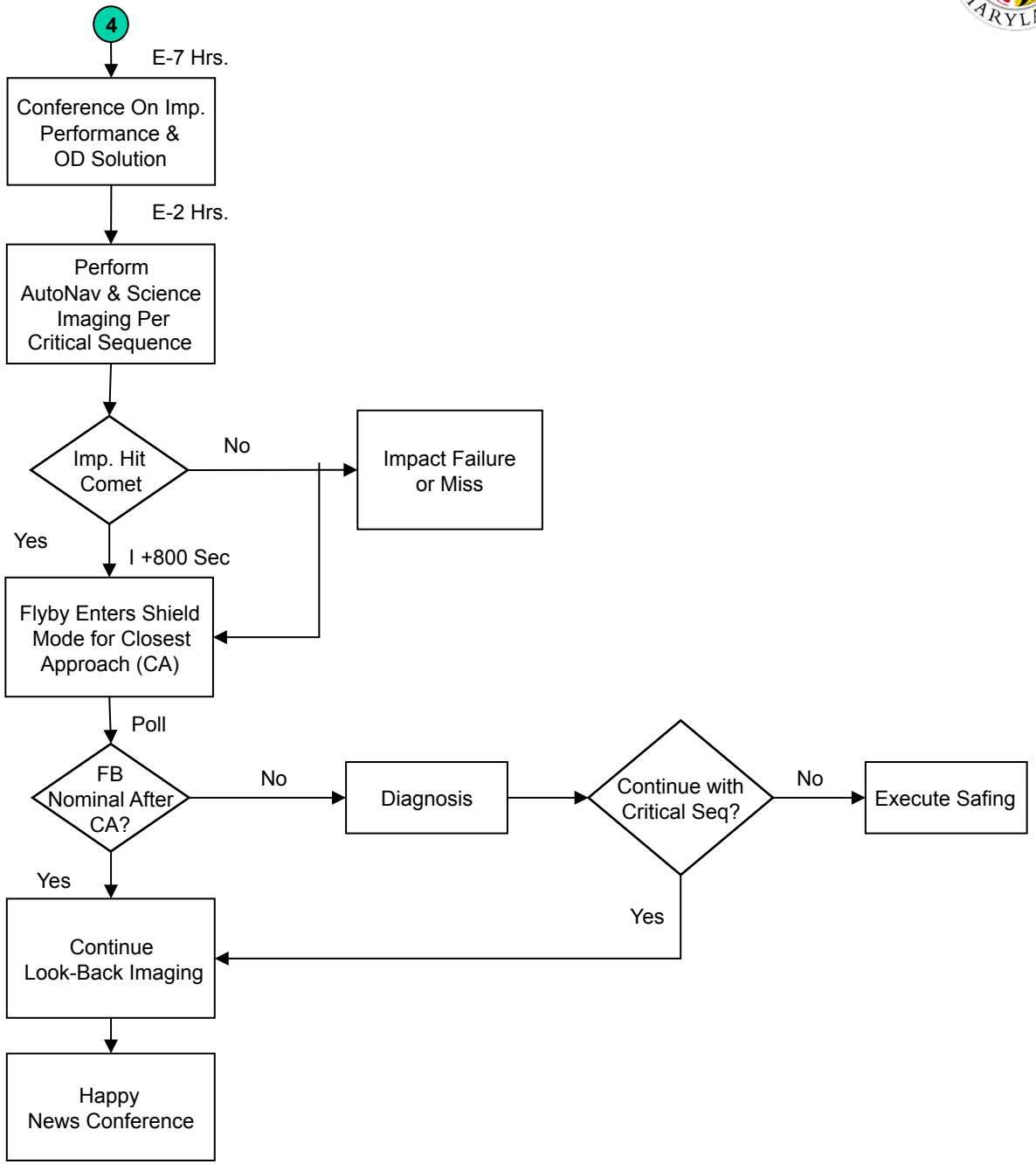
Flt. Sys. Impact Statistics **> 90%**

NOMINAL

(Criteria)

Possible Failure Modes:

- Incorrect FP Enable/Disable Settings [Low]
- AutoNav Spoof by Cosmic Rays [Low]
- Solar Flare [Low to Medium]
- S-Band Failure [Low]
- Particle Hits on Flyby at Closest Approach [Low]
- Hot Pixels Form in MRI or ITS Center of CCD Area = AutoNav Failure [Low]
- HRI or MRI Failure [Negligible]



Enough Said!