Comparison of ESA and NASA Acquisition Approaches and their Potential Effects on Science Mission Development Duration and Schedule Change

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Outline

- Introduction
- Description of Acquisition Approach
  - NASA
  - ESA
  - Primary differences in ESA and NASA Approach
- Description of Data Set
  - NASA
  - ESA
- Comparison of Formulation and Development Durations
  - vs. Mission type (Earth orbiting vs. non-Earth orbiting)
  - vs. Mission Class (Small, Medium, Large)
  - vs. Science Theme
  - vs. Complexity (CoBRA)
- Comparison of Change of Formulation and Development Duration
  - From the start of formulation/start of Phase B (i.e. KDP-B/SRR) – ESA B2 Start vs. NASA KDP-B
  - From the start of implementation /start of Phase C (i.e. KDP-C/PDR) – ESA PDR vs. NASA PDR
- Explanation of Potential Differences in Development Durations
- Recommendations on Schedule Containment and/or Schedule Guidance (i.e. estimating)
- Summary

Introduction

- Although there are many similarities in the manner in which ESA and NASA develop and acquire robotic (non-human) science missions, there are some notable differences
- This study compares and contrasts the acquisition approaches of ESA and NASA science missions to identify these differences and, further, quantitatively assesses their planned and actual development durations to determine if there are any significant differences in overall schedule length or change
- A comparison is made across various mission types, science themes, mission classes, and overall complexity to determine if differences can be identified
- In addition, a comparison is made across formulation and development phases to understand if the length and change of these phases is substantially divergent between ESA and NASA acquisitions
- Finally, an explanation of the potential reasons for these dissimilarities and recommendations for schedule guidance and containment are provided

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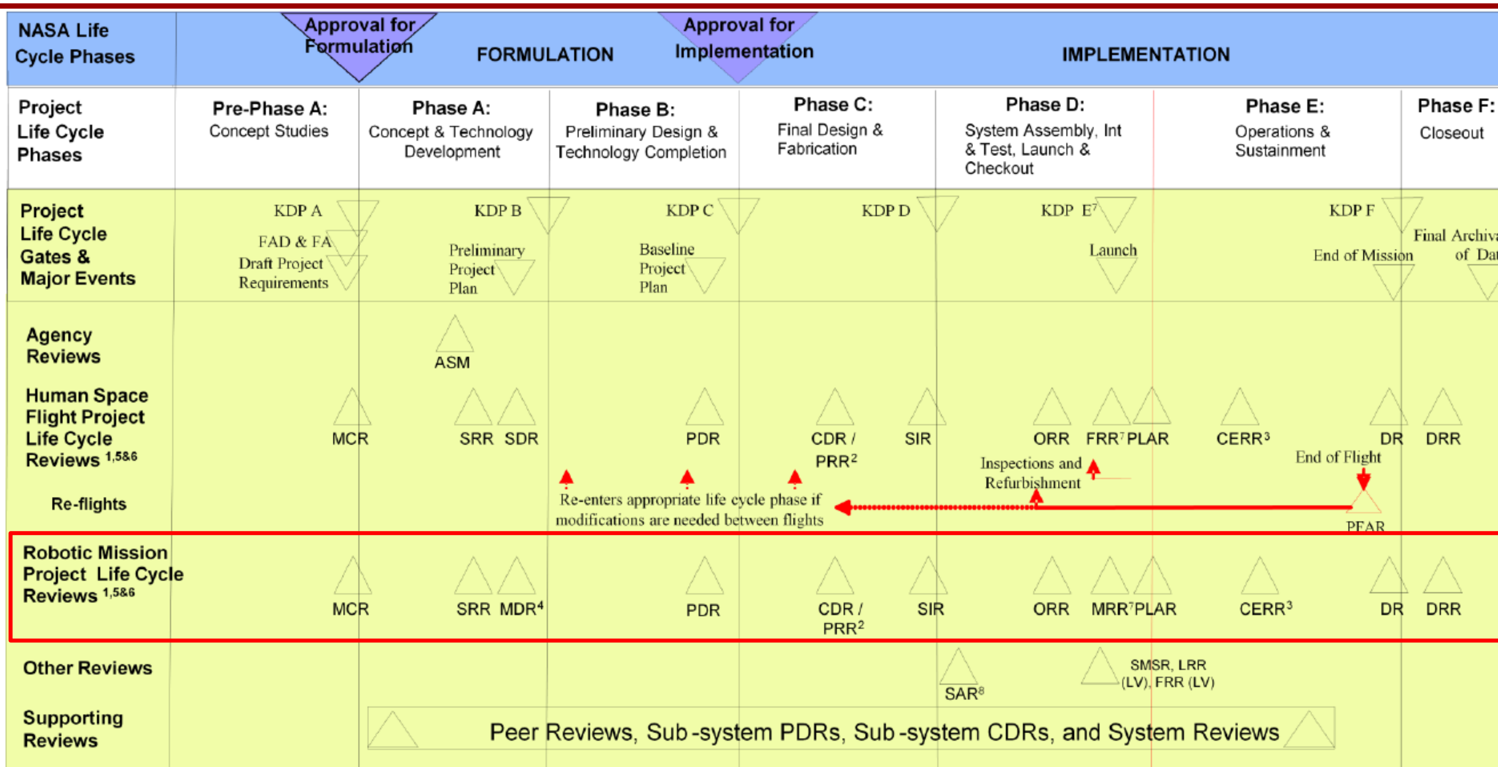
NASA Acquisition Guidance*



FOOTNOTES

1. Flexibility is allowed to the timing, number and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. PRR is needed for multiple system copies. Timing is notional.
3. CERRs are established at the discretion of program offices.
4. For robotic missions, the SRR and the MDR may be combined.
5. Single-project programs will follow the project life cycle, but will include draft/final PCAs at KDPs B and C, respectively, and draft/final Program Plans at SRR and SDR, respectively.
6. Life Cycle Review (LCR) objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-4.
7. The KDP E decision is made at the conclusion of FRR for human space flight and the MRB for robotic space flight. These meetings constitute the PMC meetings. The FRR/MRR/MRB are part of a series of events leading to approval to launch. (See the NASA Program and Project Management Handbook
8. SAR only applies to human space flight.

ACRONYMS

ASP - Acquisition Strategy Planning Meeting
ASM - Acquisition Strategy Meeting
CDR - Critical Design Review
CERR - Critical Events Readiness Review
DR - Decommissioning Review
DRR - Disposal Readiness Review
FA - Formulation Agreement
FAD - Formulation Authorization Document
FRR - Flight Readiness Review
KDP - Key Decision Point
LRR - Launch Readiness Review
MCR - Mission Concept Review
MDR - Mission Definition Review
MRB - Mission Readiness Briefing
MRR - Mission Readiness Review
ORR - Operational Readiness Review
PDR - Preliminary Design Review
PFAR - Post-Flight Assessment Review
PLAR - Post-Launch Assessment Review
PRR - Production Readiness Review
SAR - System Acceptance Review
SDR - System Definition Review
SIR - System Integration Review
SMSR - Safety and Mission Success Review
SRR - System Requirements Review

* Note: NASA Interim Directive NID-7120-97, NASA Space Flight Program and Project Management Requirements

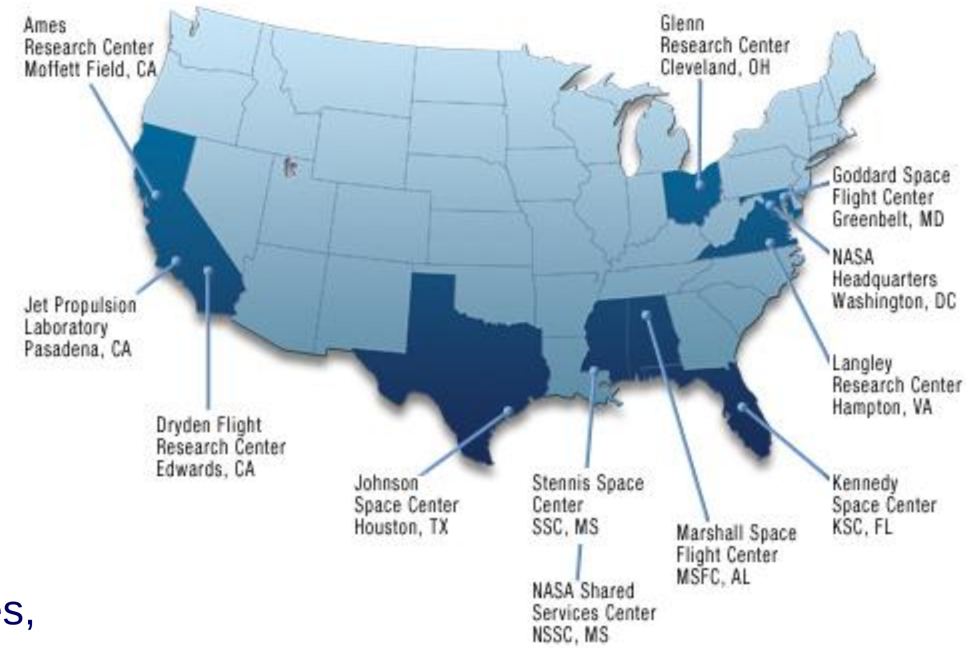
NASA Acquisition Approach

- Key Decision Point-A (KDP-A) initiates Conceptual Design Phase A
  - Preceded by Mission Concept Review (MCR)
  - Culminates in Mission Design Review (MDR)
- KDP-B initiates Preliminary Design Phase B
  - Culminates in Preliminary Design Review (PDR)
- KDP-C follows PDR and initiates detailed Design Phase C
  - Critical Design Review (CDR) occurs during Phase C
  - Culminates in Systems Integration Review (SIR)
- KDP-D follows SIR and initiates Integration and Test Phase D
  - Environmental testing and ship to launch site occurs during Phase D
  - Phase D ends after commissioning and handoff to Mission Operations team

- Team is typically set by start of Phase A
  - Bus provider, however, may join team later in process
- Requirements are typically initially established during Phase A
- Initial planning budget is set as range at KDP-B
- Final Execution budget and programmatic/technical baseline is established at KDP-C for internal and external stakeholders
  - Although some fixed price contracts are awarded for elements, contracts are typically cost plus

Additional NASA Acquisition Considerations

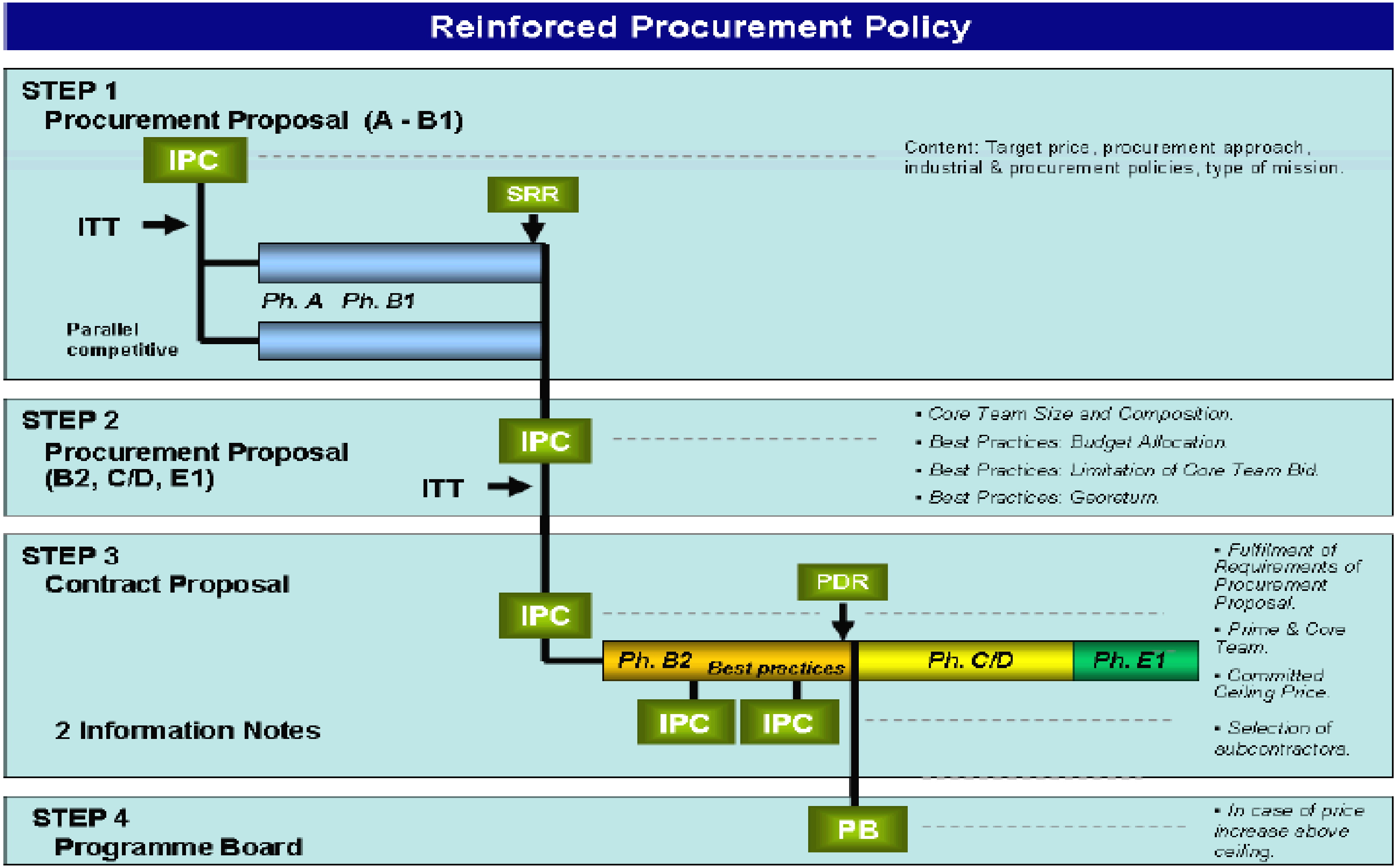
- NASA's vision is to reach for new heights and reveal the unknown so that all that can be learned will benefit all humankind*
- NASA consists of mission directorates focusing on aeronautics research, human exploration and operations, and robotic science research
- NASA is organized around Flight and Research Centers geographically spread throughout the U.S.
- NASA Centers can both act as a procurement center, where Industry acts as primary developer and integrator, or as a primary developer and integrator themselves, building and integrating the mission in-house
- For large scale projects, NASA typically utilizes the expertise of multiple Centers to address the technical challenges that projects may face



As taken from http://osbp.nasa.gov/about.html

* Note: As taken from http://www.nasa.gov/about/highlights/what_does_nasa_do.html

ESA* Acquisition Guidance



* Graphic reproduced with permission of the European Space Agency

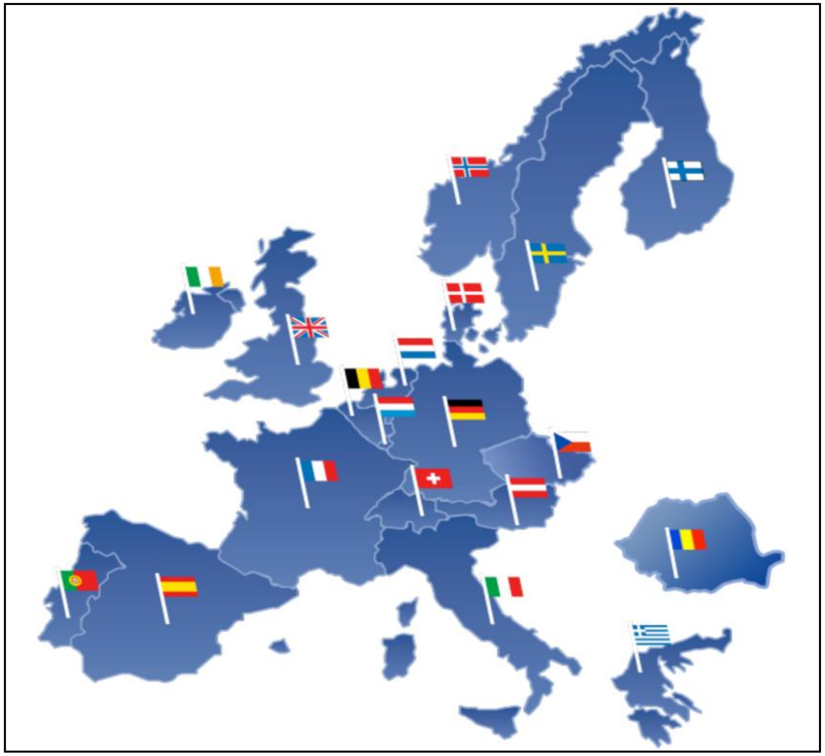
ESA Acquisition Approach

- Step 1: Procurement Phase System Definition Studies, covering Phases A / B1:
  - Competitive Phase A1: System Concept Definition, and Phase B1: System Concept Consolidation through to complete System Requirements Review (SRR)
  - Typically more than one mission team/contractor working though Phase A1 and B1
- Step 2: Procurement Proposal
  - Proposal phase for developing project and down-selection to one contractor
- Step 3: Contract Proposal
  - Phase B2 is preliminary design
  - Phases C / D are similar to NASA for detailed design, fabrication, assembly, integration and test
- Step 4: Programme Board
  - Authorizes final budget
  - Convened if budget needs to be increased above Ceiling Price determine in Step 3

- Study Phase A / B1 are typically competitive (2 parallel Firm Fixed Price contracts)
- Phase B2 awarded to single winner to start preliminary design. (Firm Fixed Price for Phase B2 and Ceiling Price to be Converted to firm Fixed Price for Phase C/D/E1)
- Price is not established with external stakeholders until after Phase B2 is complete
- Phase C / D is typically Firm Fixed Price (FFP) contract with roles/sharing agreed by all ESA partner Member States

Additional ESA Acquisition Considerations

- ESA's purpose shall be to provide for, and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications
- ESA current includes 19 Member States
- Many of ESA acquisitions typically include participation from multiple Member States
- ESA’s activities fall into two categories – ‘mandatory’ and ‘optional’*
  - Programmes carried out under the General Budget and the Science Programme budget are ‘mandatory’ . All Member States contribute to these programmes on a scale based on their Gross Domestic Product (GDP).
  - The other programmes, known as ‘optional’, are only of interest to some Member States, who are free to decide on their level of involvement



As taken from http://www.esa.int/images/ESA_MS_flags.jpg

* Note: As taken from http://www.esa.int/esaMI/About_ESA/SEMNQ4FVL2F_0.html

Comparison of Acquisition Approaches

- Overall approach is similar
  - ESA and NASA Phases are similar in terms of Phase A Conceptual Design, Phase B Preliminary Design, and Phase C/D Detailed Design and Implementation
- Primary differences are in Phase B and Phase C/D
  - ESA Phase B is comprised of a competitive Phase B1 and separate Phase B2
    - ESA Phase B2 is similar to NASA Phase B
  - ESA Phases C / D are similar in content to NASA but ESA's contracts are typically Firm Fixed Price
    - Additionally role/sharing must be agreed by all ESA partner Member States
- Differences in roles and services that are acquired by the Agencies
  - NASA often serves in the integrator role for science missions
  - ESA typically has the prime contractor serve in the integrator role
- Question:
  - Given differences in Phase B and Phase C/D, is there a difference in schedule duration and schedule change for ESA and NASA missions?

- Study Approach:
  - Compare average schedule durations for ESA Phase B2/C/D vs. NASA Phase B/C/D
  - Compare schedule change percentage for ESA Phase B2/C/D vs. NASA Phase B/C/D

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Selection Criteria for Science Mission Data Sets

- Select a cross section of missions from each of the science themes
  - Planetary
  - Heliophysics (NASA) / Earth science (ESA)
  - Earth Science (NASA) / Earth Observation (ESA)
  - Astrophysics
- Select a cross section of missions that had fixed launch windows vs. non-fixed launch windows
  - Fixed Launch window (Planetary missions that have some launch window constraint)
  - Non-Fixed launch window
- Select a cross section of missions from different mission classes, where mission class is defined by the Phase B/C/D cost (NASA) or Phase B2/C/D cost (ESA) of the mission including Launch vehicle, in USD FY$10
  - *Small* (<$250M)
  - *Medium* ($250M > $ < $750M)
  - *Large* (> $750M)
- Select a set of missions, ideally between 20 and 30 in number, that were delivered for launch (successful or impaired but not failed)
  - For NASA the data set was targeted for missions launched after the year 2000
  - For ESA the data set includes some pre-2000 missions to ensure a larger sample size

NASA Science Mission Data Set Composition

Mission Name	Launch Year	Orbit Type	Science Type	Mission Class
Genesis *	2001	Non-EO	Planetary	Medium
MAP	2001	Non-EO	Astrophysics	Small
RHESSI	2002	EO	Heliophysics	Small
GRACE	2002	EO	Earth Science	Small
Aqua	2002	EO	Earth Science	Large
ICESAT	2003	EO	Earth Science	Medium
GALEX	2003	EO	Astrophysics	Small
MER *	2003	Non-EO	Planetary	Large
Spitzer	2003	EO	Astrophysics	Large
Aura	2004	EO	Earth Science	Large
MESSENGER *	2004	Non-EO	Planetary	Medium
Swift	2004	EO	Astrophysics	Medium
Deep Impact *	2005	Non-EO	Planetary	Medium
MRO *	2005	Non-EO	Planetary	Medium
New Horizons *	2006	Non-EO	Planetary	Medium
CloudSat	2006	EO	Earth Science	Medium

Mission Name	Launch Year	Orbit Type	Science Type	Mission Class
STEREO	2006	EO	Heliophysics	Medium
AIM	2007	EO	Heliophysics	Small
THEMIS	2007	EO	Heliophysics	Small
Phoenix *	2007	Non-EO	Planetary	Medium
Dawn	2007	Non-EO	Planetary	Medium
GLAST	2008	EO	Astrophysics	Medium
IBEX	2008	EO	Heliophysics	Small
OCO	2009	EO	Earth Science	Medium
Kepler	2009	EO	Astrophysics	Medium
LRO	2009	Non-EO	Planetary	Medium
WISE	2009	EO	Astrophysics	Medium
SDO	2010	Non-EO	Heliophysics	Large
Glory	2011	EO	Earth Science	Medium
Juno *	2011	Non-EO	Planetary	Large
GRAIL	2011	Non-EO	Planetary	Medium
MSL *	2011	Non-EO	Planetary	Large

- NASA Mission Distribution – 32 Mission Total
  - Orbit: 18 Earth Orbiting (EO), 14 Non-Earth Orbiting (Non-EO)
  - Science: 7 Astrophysics, 12 Planetary, 7 Earth Science, 6 Heliophysics,
  - Type: 7 Small (<$250M), 18 Medium ($250M > $ < $750M), 7 Large (> $750M)

* Note: Missions having fixed launch window constraints

ESA Mission Data Set Composition

Mission	Launch Year	Orbit Type	Science Type^	Mission Class
Giotto*	1985	Non-EO	Planetary	Medium
Hipparcos	1989	EO	Astrophysics	Medium
ERS-1	1991	EO	Earth Obs	Large
ISO	1995	EO	Astrophysics	Large
ERS-2	1995	EO	Earth Obs	Large
CLUSTER	1996	EO	Earth Science	Large
XMM-Newton	1999	Non-EO	Astrophysics	Large
Cluster II	2000	EO	Earth Science	Small
INTEGRAL	2002	Non-EO	Astrophysics	Medium
ENVISAT	2002	EO	Earth Obs	Large
Mars Express*	2003	Non-EO	Planetary	Medium
SMART-1	2003	Non-EO	Planetary	Small
Rosetta*	2004	Non-EO	Planetary	Large
Venus Express*	2005	Non-EO	Planetary	Small
CRYOSAT 1	2005	EO	Earth Obs	Small
METOP	2006	EO	Earth Obs	Large
Herschel	2009	Non-EO	Astrophysics	Large
Plank	2009	Non-EO	Astrophysics	Medium
Proba-2	2009	EO	Earth Science	Small
Cyrosat-2	2009	EO	Earth Obs	Small
GOCE	2009	EO	Earth Science	Medium

- ESA Mission Distribution – 21 Mission Total
  - Orbit Type:
    - 12 Earth Orbiting (EO),
    - 9 Non-Earth Orbiting (Non-EO)
  - Science Type
    - 6 Astrophysics
    - 5 Planetary
    - 6 Earth Observation
    - 4 Earth Science
  - Mission Class:
    - 6 Small (<$250M),
    - 6 Medium ($250M > $ < $750M),
    - 9 Large (> $750M)

^ Note:
- ESA Earth Science = NASA Heliophysics
- NASA Earth Science = ESA Earth Observation

* Note: Missions having fixed launch window constraints

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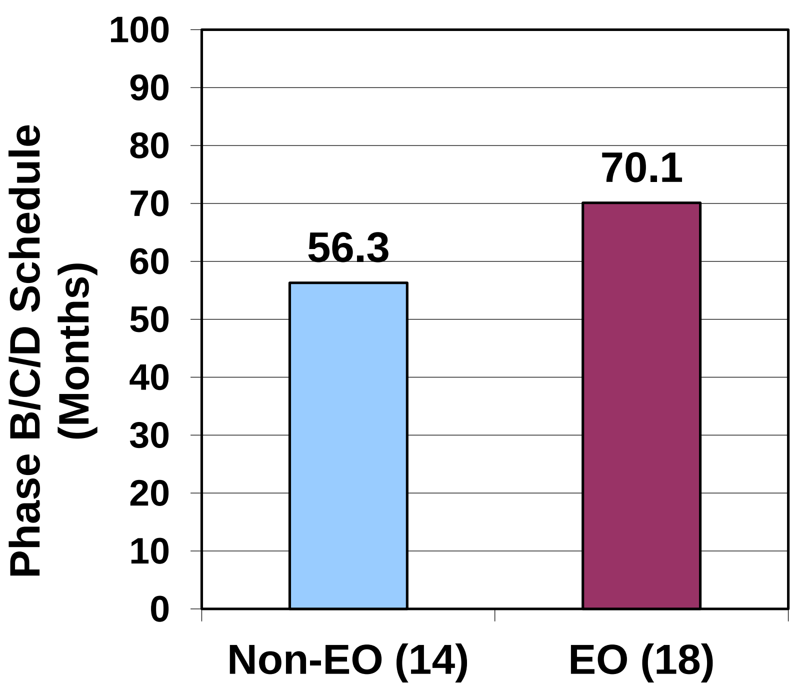
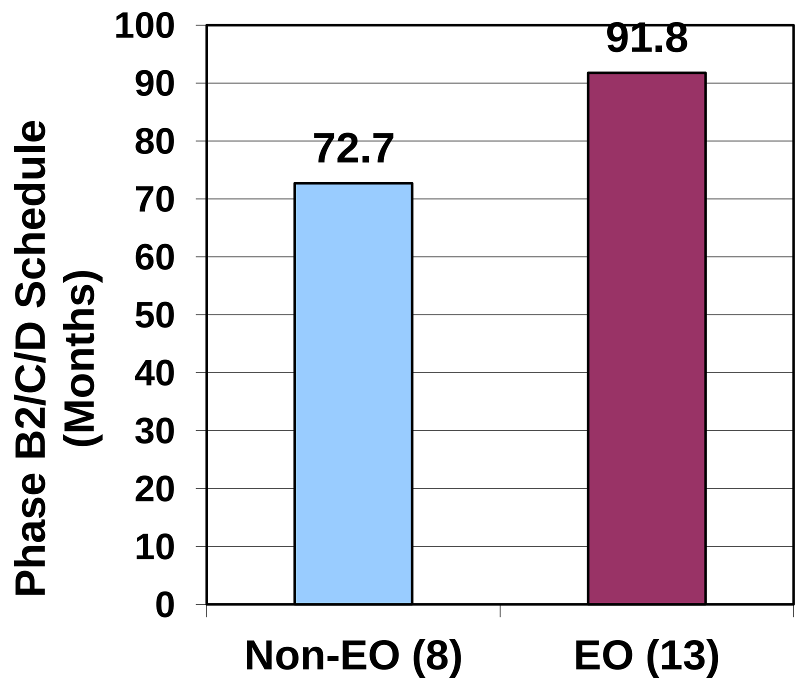
Average Schedule Duration vs. Orbit Type

NASA Average Schedule Durations



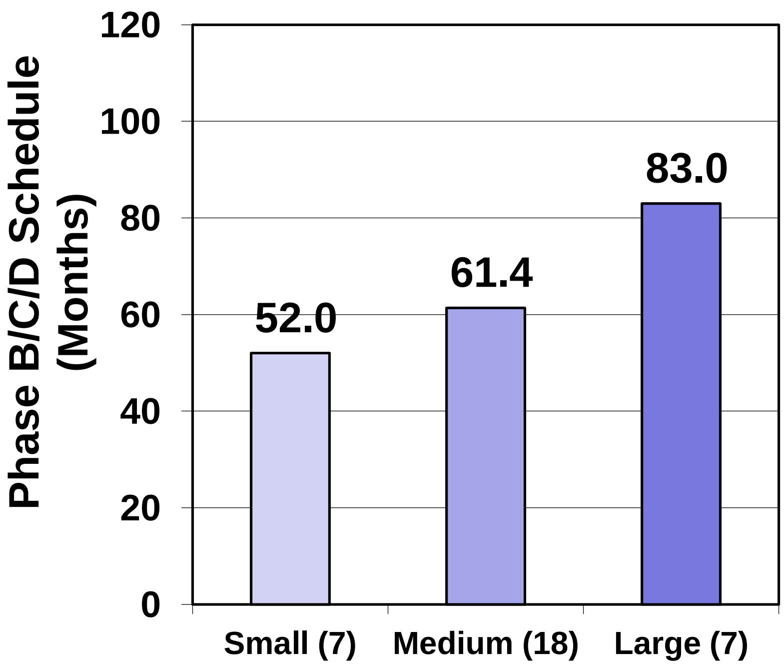
ESA Average Schedule Durations



For the data set, on average, ESA mission schedule durations are longer than NASA's

Average Schedule Duration vs. Mission Class

NASA Average Schedule Durations



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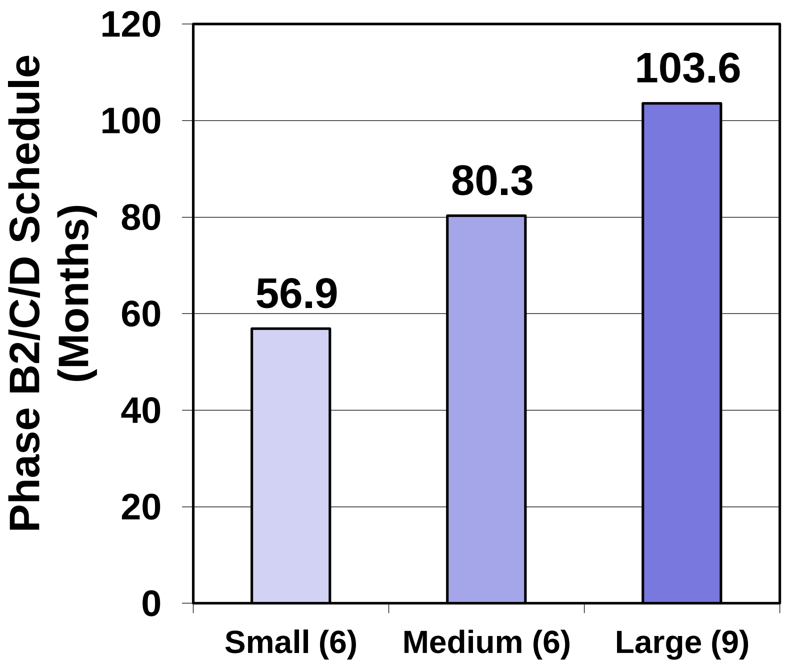
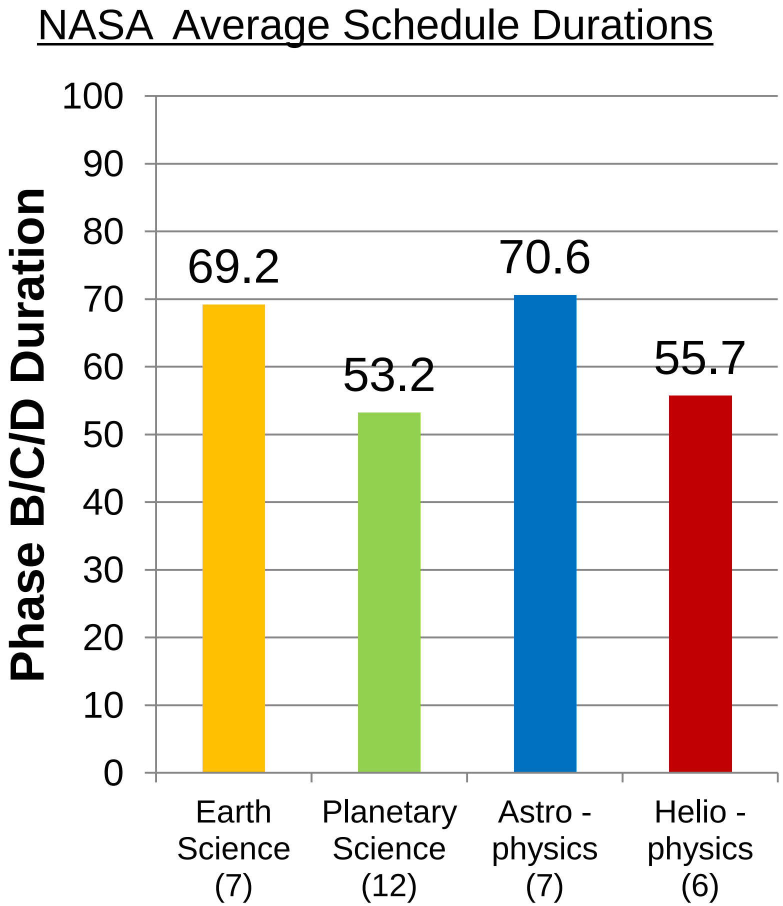
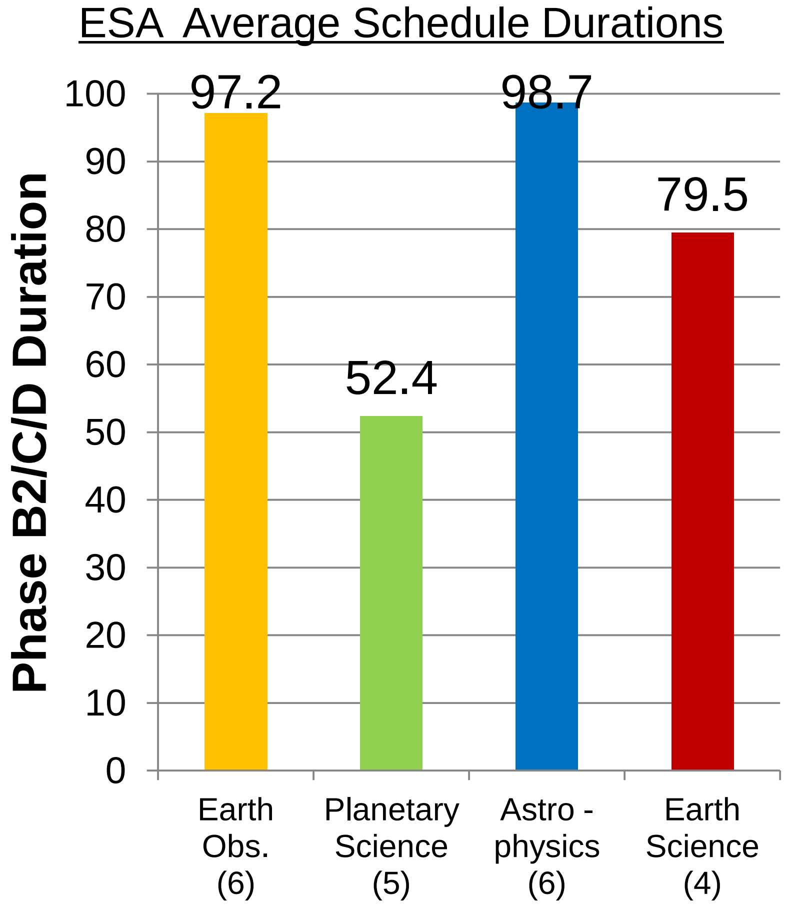


- Mission Class Definition based on Phase B/C/D cost including Launch Vehicle
  - ***Small*** (<$250M), ***Medium*** ($250M > $ < $750M), ***Large*** (> $750M), USD FY$10

For the data set, for smaller mission class, ESA and NASA mission schedule durations are similar

Average Schedule Duration vs. Science Theme*





For the data set, for planetary missions, ESA and NASA mission schedule durations are similar; for other themes, ESA durations are longer

* Note: ESA Earth Science = NASA Heliophysics; NASA Earth Science = ESA Earth Observation

Observations about the Schedule Durations

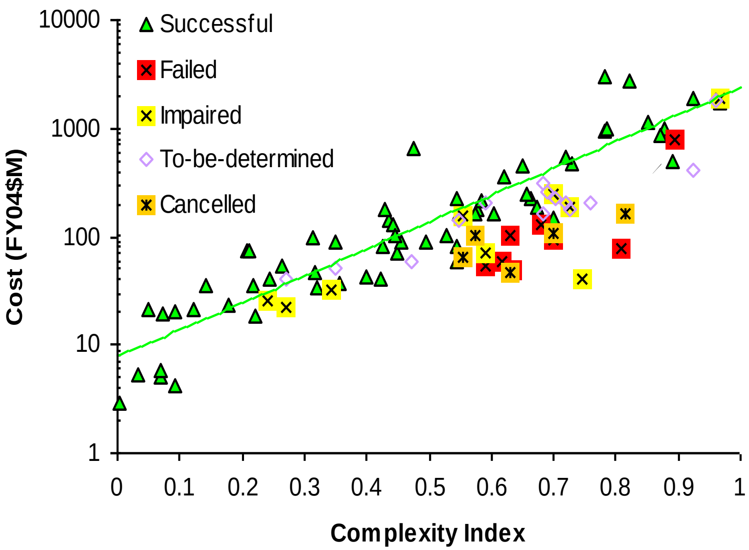
- The lower planetary mission development durations show that both Agencies can manage and deliver to minimal schedules
  - Both ESA and NASA, on average, deliver around 53 months
- ~53 months appears to be the minimum schedule that is achievable
  - Could be used as a guideline for an un-compressible lower limit
- This suggests that having a **clear, highly visible,** and **urgent** goal and/or milestone **shared by all stakeholders** is one way to maintain and manage to schedule
- The planetary data provides some interesting insights about managing to schedule

Complexity Based Risk Assessment (CoBRA) Overview*

- Cost & schedule shown independently versus Complexity
  - High correlation between complexity and cost is apparent
  - Average cost and schedule of impaired and failed missions is higher than that of successful missions for the same complexity
  - Good correlation between complexity and schedule

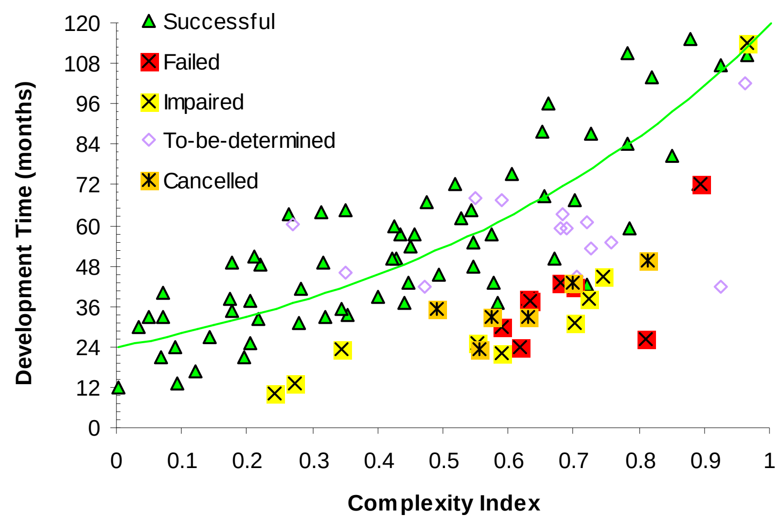
Cost vs. Complexity**

Not considered for this study



Schedule vs. Complexity**

Included in this study



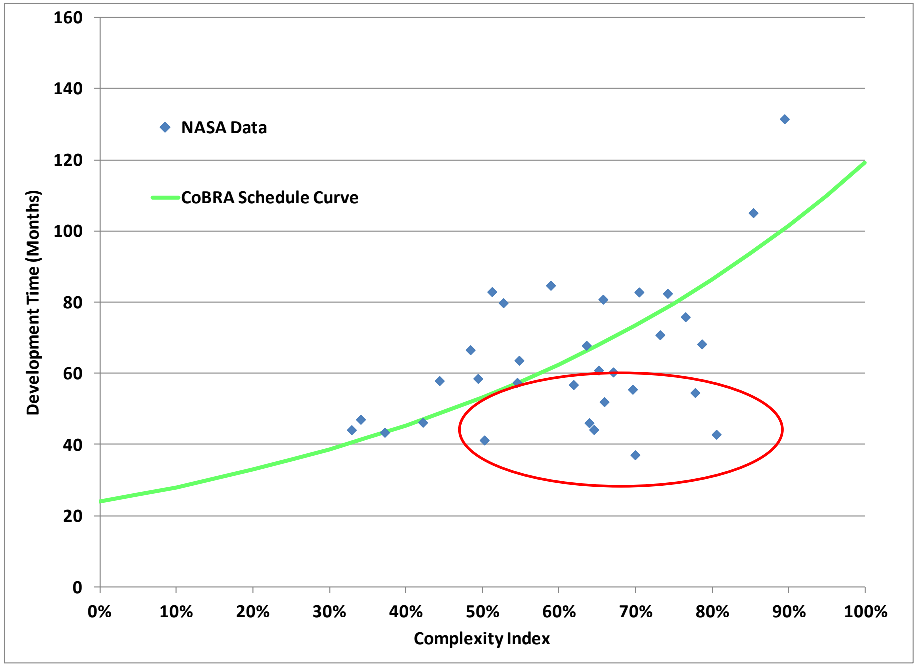
* "Perspectives on NASA Robotic Mission Success with a Cost and Schedule-constrained Environment," Bearden, D.A., Aerospace Risk Symposium, Manhattan Beach, CA, August 2005.

** Includes over 140 recent (>1989) U.S. built missions –incl. NASA, DOD

NASA & ESA Schedule vs. Complexity

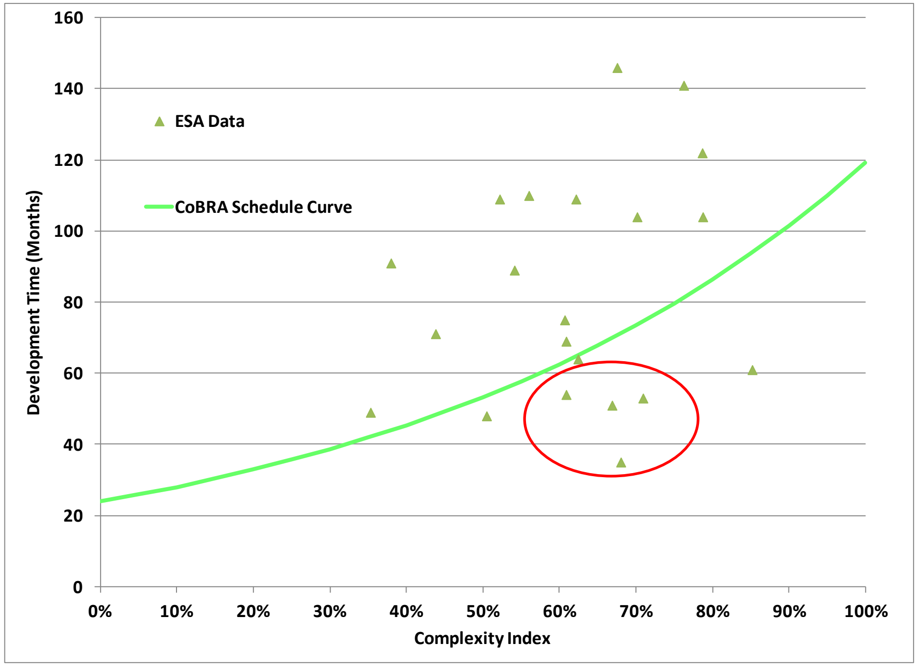
NASA Schedule vs. Complexity

Average Complexity = 61.7%



ESA Schedule vs. Complexity

Average Complexity = 61.9%

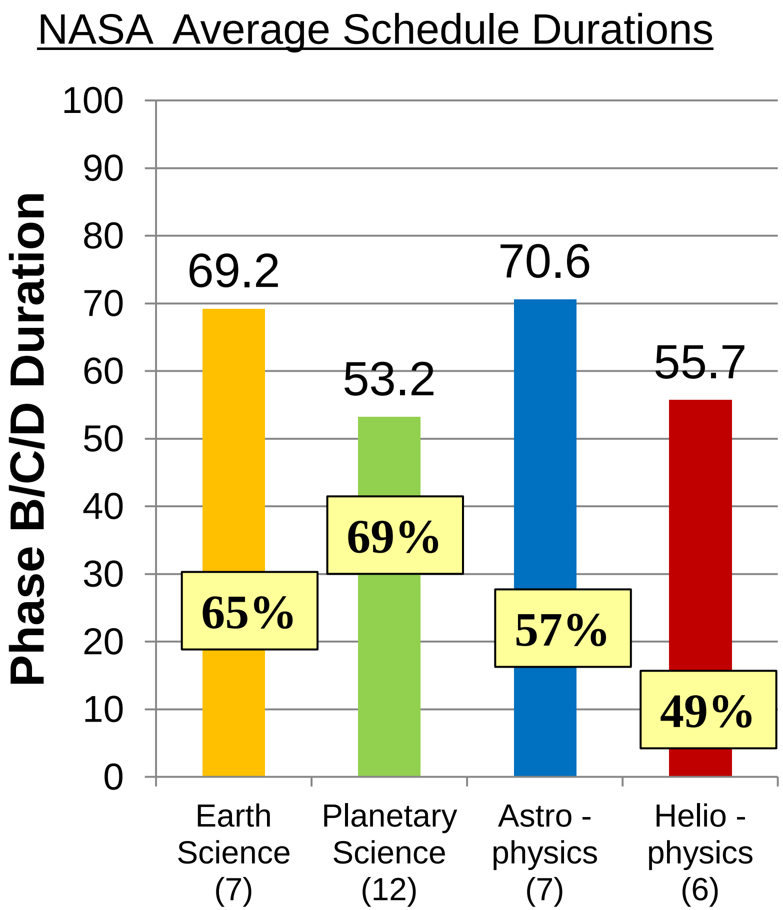


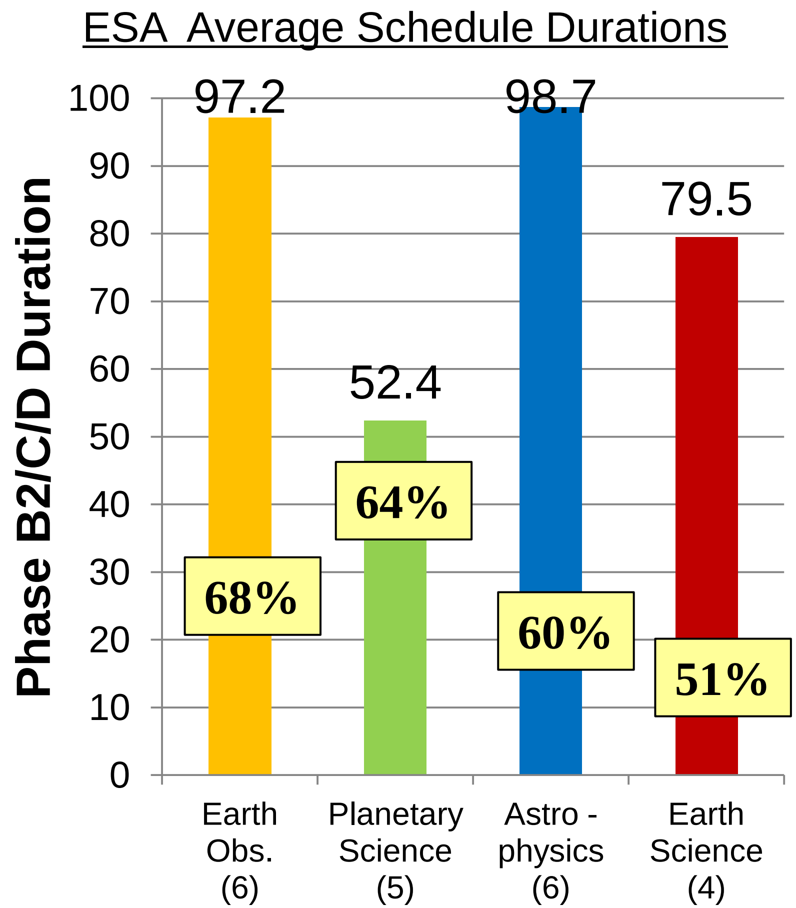
For the data set, the ESA and NASA missions show more dispersion as a function of Complexity than the larger U.S. mission (over 140) derived "Green line"

*Planetary mission cloud

AEROSPACE

Average Schedule Duration vs. Science Theme* vs. Complexity Average





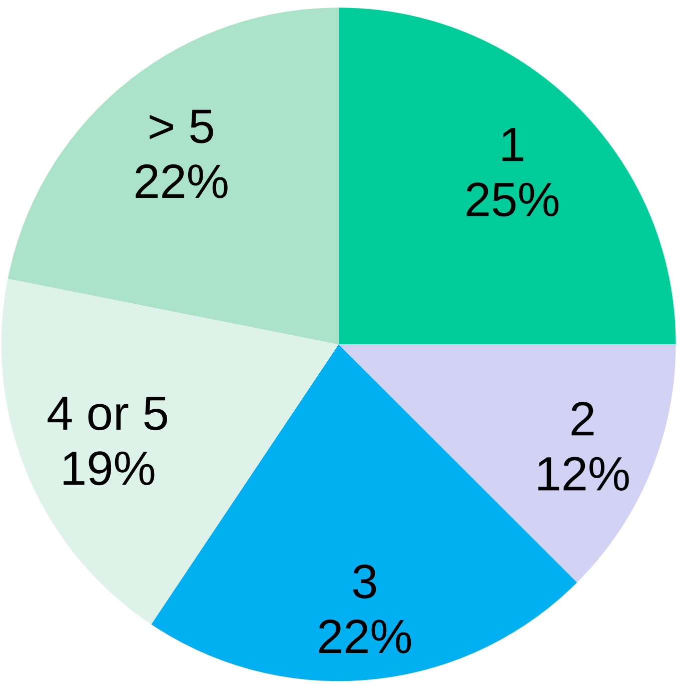
For the data set, by Theme, ESA missions are of similar complexity to NASA missions

* Note: ESA Earth Science = NASA Heliophysics; NASA Earth Science = ESA Earth Observation

Average Number of Instruments Per Mission

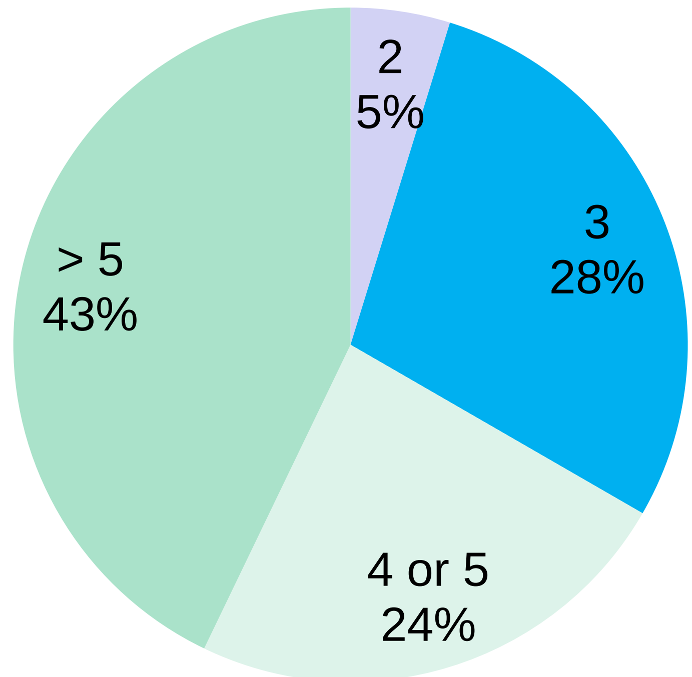
NASA Average # of Instruments/Mission

Average = 3.6 instruments/mission



ESA Average # of Instruments/Mission

Average = 6.1 instruments/mission



For the data set , ESA Missions have a larger number of instruments and a greater number participants which can make ESA missions organizationally more complicated

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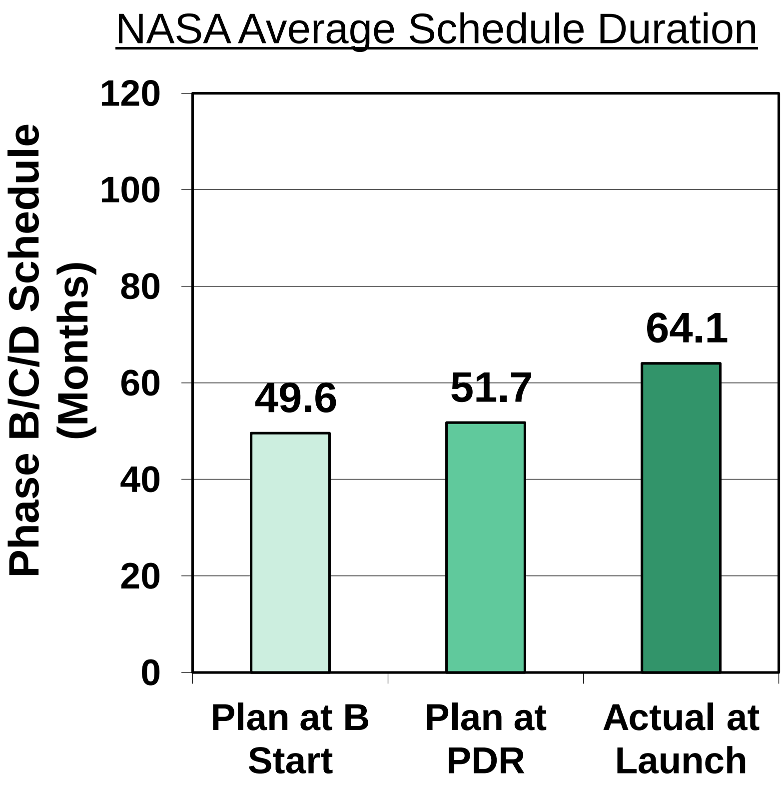
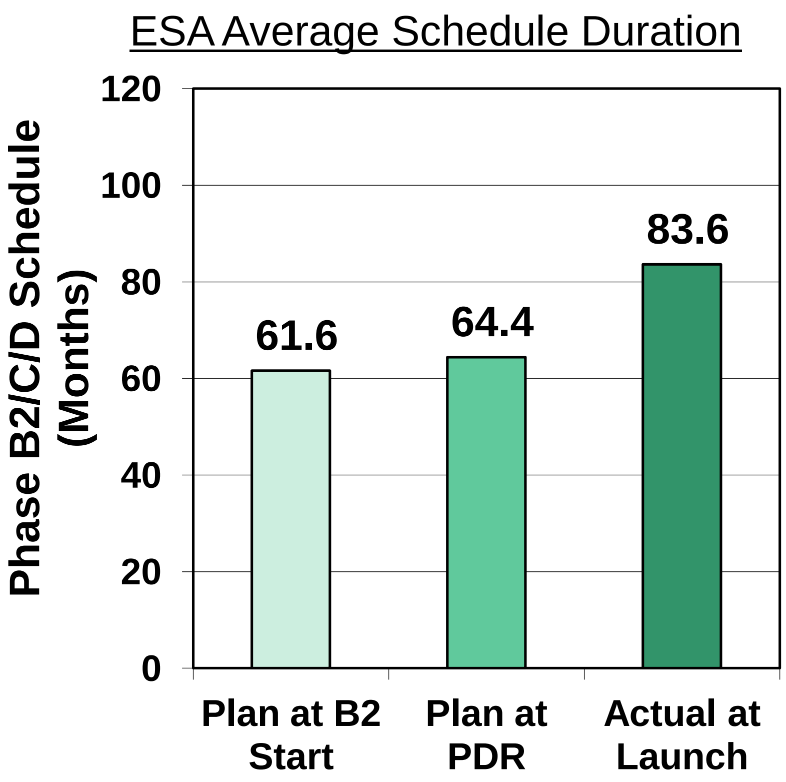
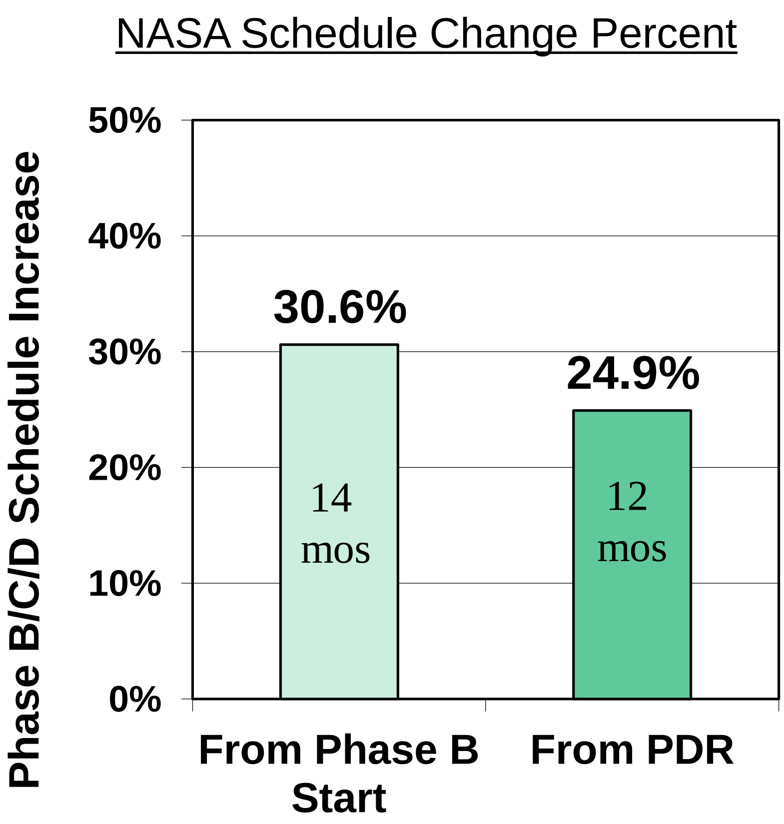
Evolution of Average Planned vs. Actual Schedule Durations

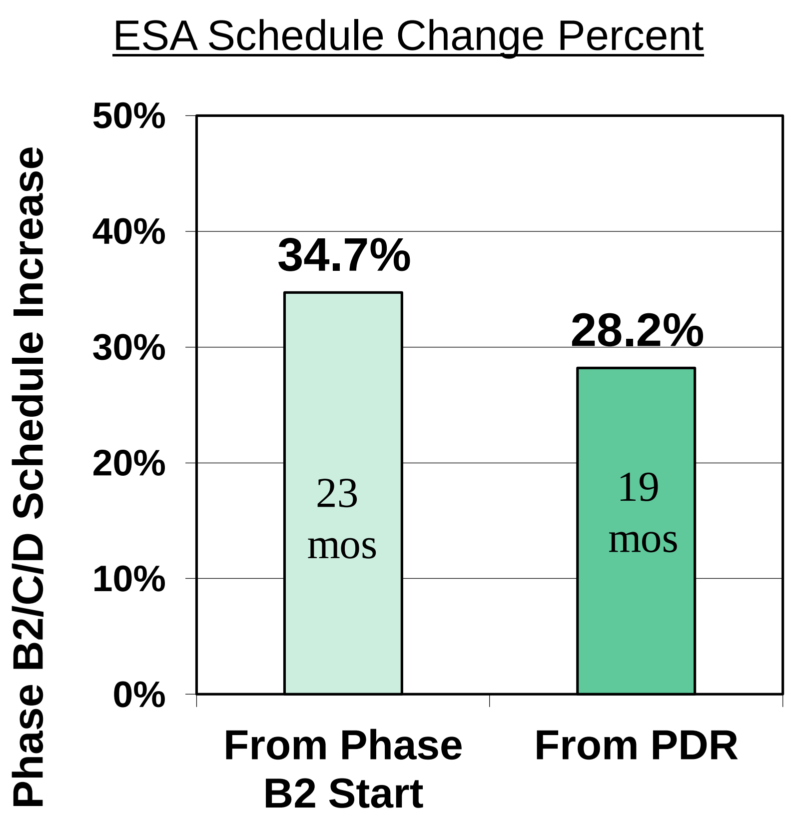




For the data set, ESA initial planned schedule durations are more similar to NASA on average; Larger change results in greater difference for final, actual durations

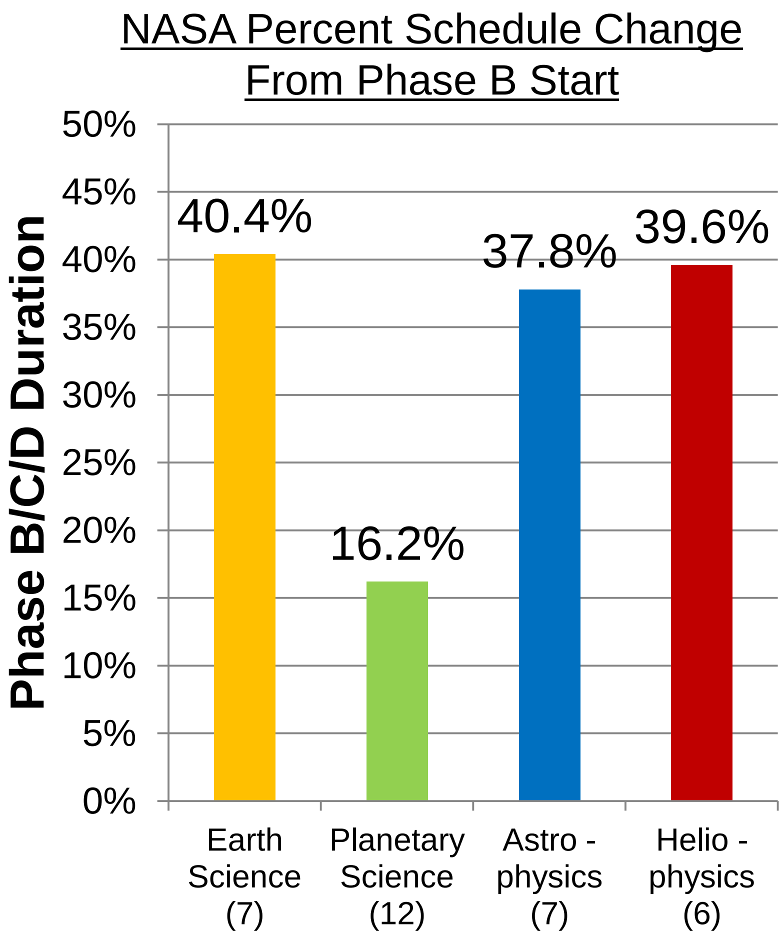
Comparison of Average Schedule Change

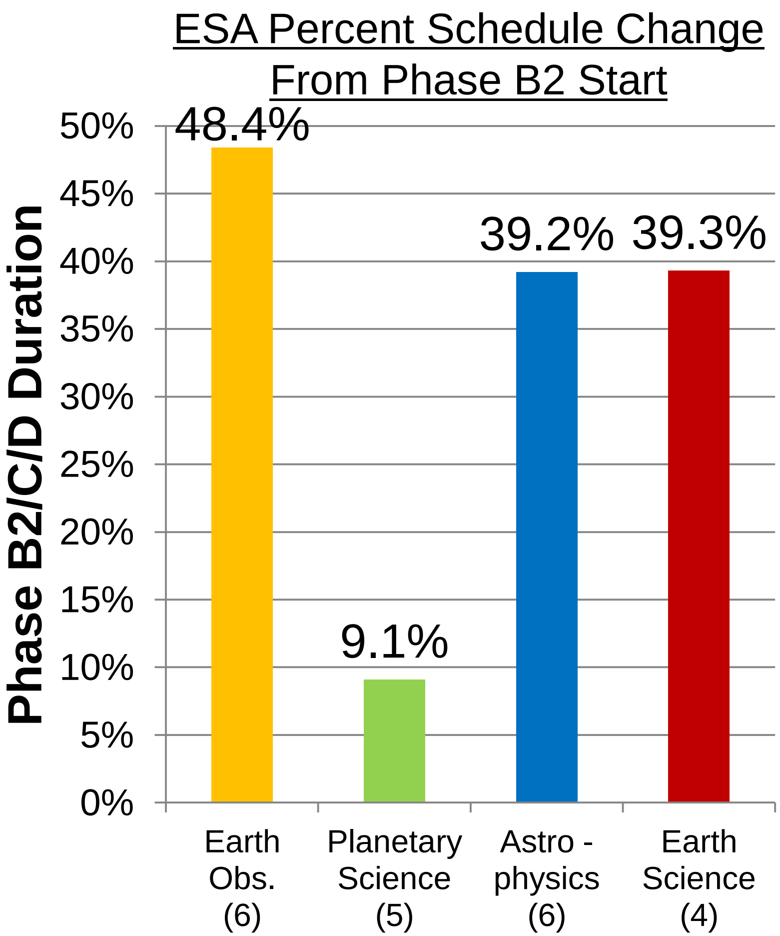




For the data set, percentagewise, ESA schedule change performance is similar to NASA schedule change performance; absolute schedule change is ~2 years for ESA relative to ~1 year for NASA

Average Schedule Change vs. Science Theme*





For the data set, planetary schedule change is lowest for both ESA & NASA

* Note: ESA Earth Science = NASA Heliophysics; NASA Earth Science = ESA Earth Observation

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Potential Explanation of Differences in Durations and Change (1 of 2)

- Higher average mission schedule duration for ESA relative to NASA
  - For the data set, many ESA missions are larger (>$750M FY$10 USD mission class) and have a greater number of organizational participants than the NASA missions in the data set
    - ESA's charter to implement mandatory missions that require all Member States to participate in order to provide the necessary expertise to ensure mission success contributes to the greater organizational intricacy of ESA missions
    - For the data set, the ESA missions typically included at least 3 countries for the primary mission, and 12 countries on average as subcontractors or payload contributors
  - For the data set, the ESA missions had a higher number of instruments, on average 6 instruments whereas NASA missions average less than 4 instruments per mission
  - Difficulty of meeting multiple requirements and interests may add to schedule challenge
- ESA's risk avoidance posture may also contribute to longer schedule durations and change relative to plan
  - ESA's record of never having a failed mission may contribute to the significant aversion to being the first mission to fail
  - This is in contrast to some of the NASA missions in the data set that were implemented under the more risk tolerant, Faster, Better, Cheaper paradigm

Potential Explanation of Differences in Durations and Change (2 of 2)

- Small class missions (<$250M FY$10 USD) development durations are similar
  - Smaller missions are very focused and may be easier to manage for both ESA and NASA
- Planetary missions
  - ESA and NASA both demonstrate good ability to achieve relatively short schedules when a launch window constraint is imposed by planetary/asteroid/comet mission planning considerations
- Schedule Change
  - Both ESA and NASA demonstrate ability to control schedule change when schedule performance is imperative to meet imposed launch window constraints
  - For missions with no planetary launch window constraint, schedule change performance was worse than constrained missions for both ESA and NASA missions
  - Result may imply that the urgency of meeting constrained launch windows is important in controlling schedule growth

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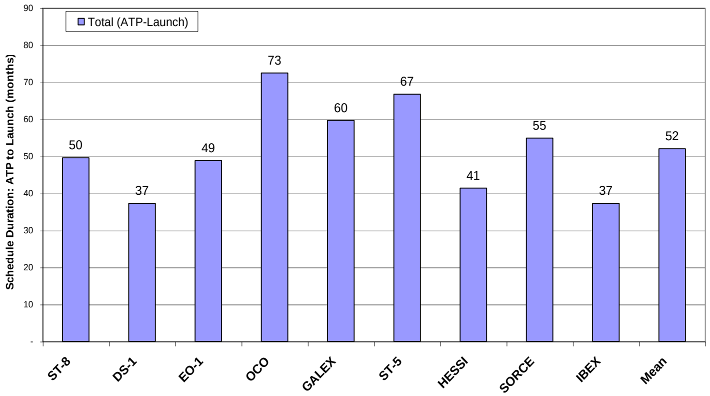
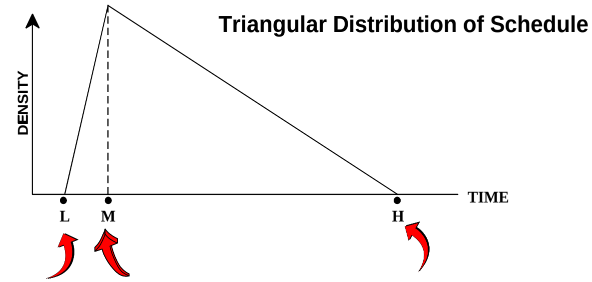
Considerations/Recommendations

- Producing World Class Science is a difficult job
  - NASA and ESA face the inherent difficulty of developing highly complex, one-of-a-kind, cutting edge missions that are associated with their charter to provide preeminent space science.
  - As such, unforeseen development difficulties will always occur that can significantly affect the planned development schedule
  - Although some schedule change can be anticipated or contained, it is extremely difficult to predict change due to development of technology that is beyond the current state of the art
- Establishing a solid baseline at NASA KDP-C or ESA Programme Board is critical in managing to budget
  - As economic conditions force a reduction in NASA and ESA budgets, the perception of "uncontrolled" cost and schedule change can lead to public pressure to reduce the budget further and may lead to a greater probability of cancelling missions that are not meeting programmatic obligations
- Schedule estimation techniques, using historical data, should be used to set more realistic plans, and set expectations, at the initiation of a project
  - Starting with a more realistic schedule can help build a more robust plan, earlier in the development cycle, so as to better manage to schedule and cost
  - Managing to the baseline schedule and cost demonstrates fiscal responsibility and accountability to NASA's and ESA's stakeholders

Independent Schedule Risk Process Overview*

Example of Multiple Schedule Estimates



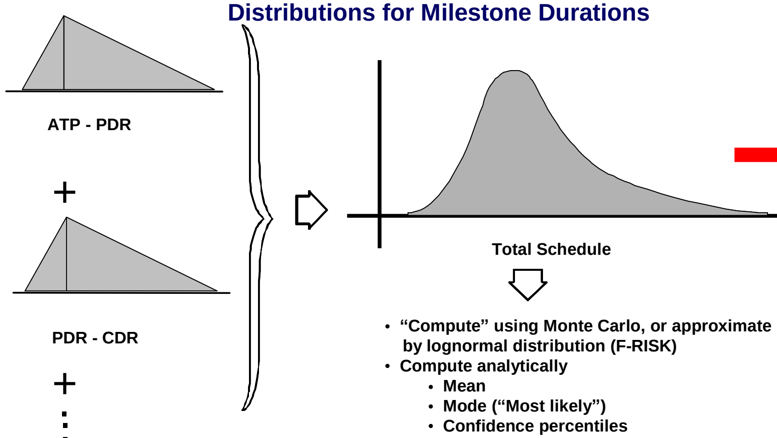


Optimistic Schedule
(Lowest Viable Estimate from Analogous Mission data)

Most-Likely Schedule (Mode)
(Average of the Analogous mission data)

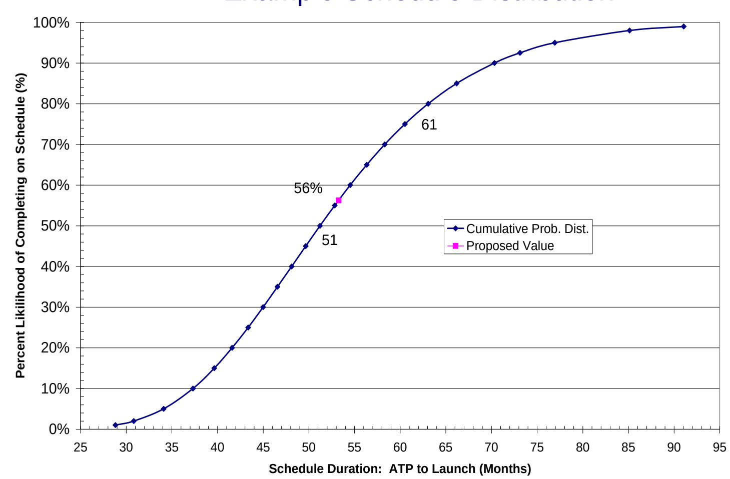
Pessimistic Schedule
(Worst Case Estimate From Analogous Mission Class data)

Total Distribution is a Combination of Schedule Distributions for Milestone Durations



- "Compute" using Monte Carlo, or approximate by lognormal distribution (F-RISK)
- Compute analytically
  - Mean
  - Mode ("Most likely")
  - Confidence percentiles

Example Schedule Distribution



* As taken from "A Quantitative Approach to Independent Schedule Estimates (ISE) of Planetary & Earth-orbiting Missions", D. Emmons, R. Bitten, 2008 ISPA/SCEA Joint International Conference & Workshop

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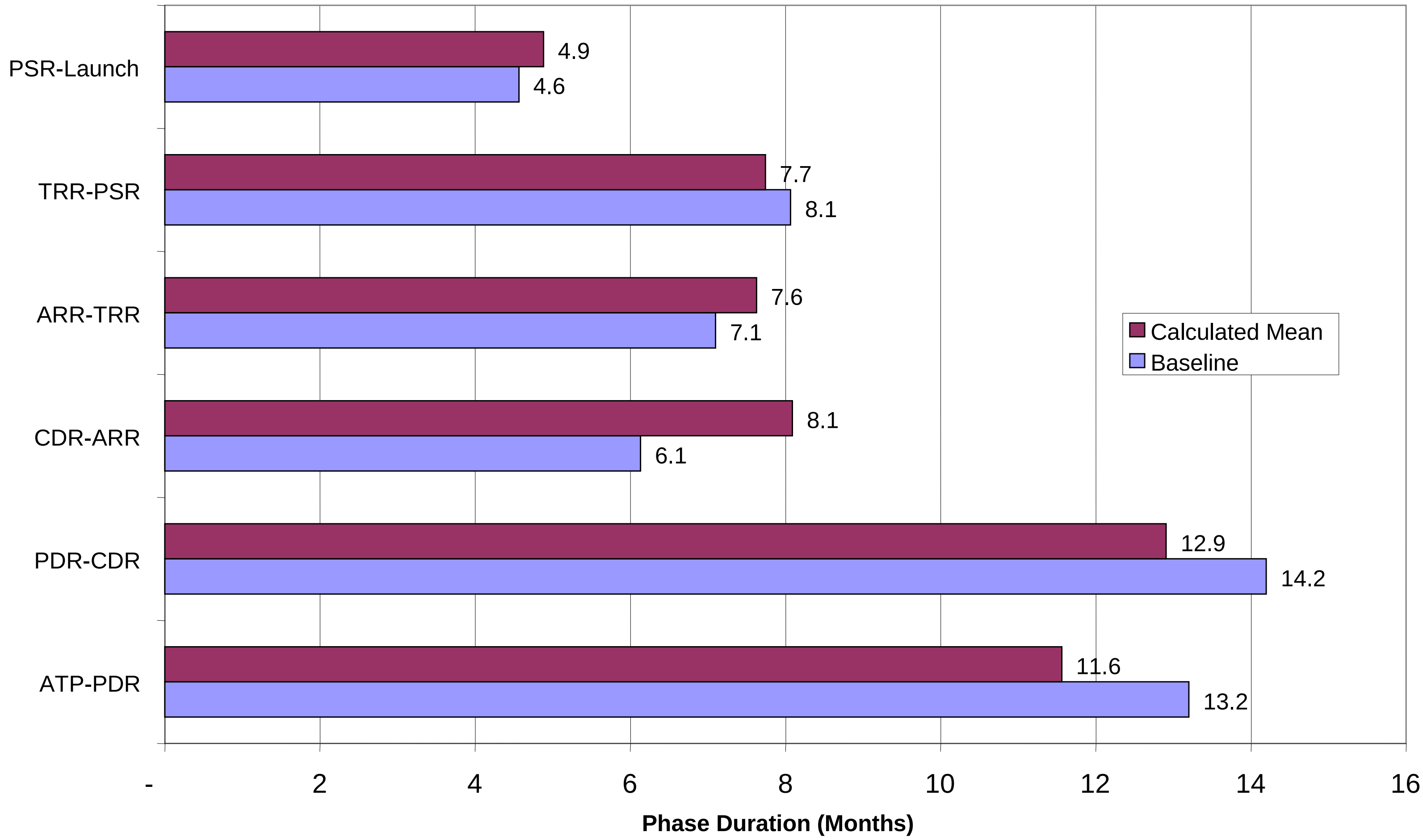
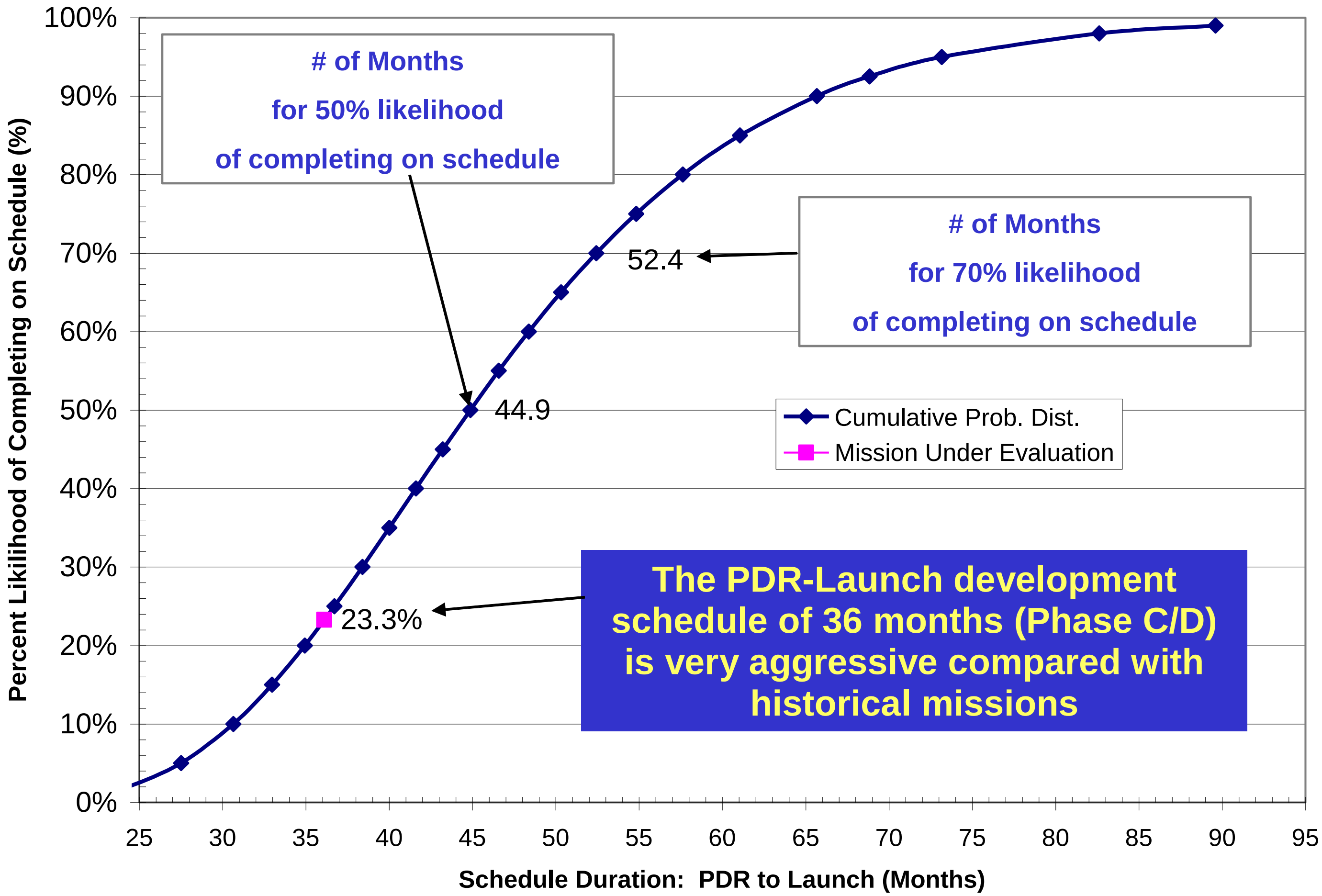
Example Comparison of Project Schedule to Calculated Mean from a Variety of Analogous Historical Missions



Provides Assessment of where Project may need more time relative to Historical Missions

* As taken from "A Quantitative Approach to Independent Schedule Estimates (ISE) of Planetary & Earth-orbiting Missions", D. Emmons, R. Bitten, 2008 ISPA/SCEA Joint International Conference & Workshop

Example Schedule Risk S-Curve Result: PDR to Launch*



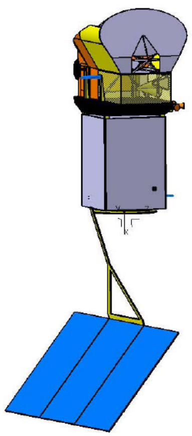
Historical Comparison Identified Limited Chance of Developing on Proposed Schedule

* As taken from "A Quantitative Approach to Independent Schedule Estimates (ISE) of Planetary & Earth-orbiting Missions", D. Emmons, R. Bitten, 2008 ISPA/SCEA Joint International Conference & Workshop

ESA Schedule Estimating Methods Overview

- ESA has developed a methodology mainly based on AHP pairwise comparisons to estimate schedule durations. The main reason for applying such methodology is that most of the schedule drivers are qualitative. The list of such drivers is provided in subsequent slides
- Two classes of estimate models have been developed:
  - Class 5 model providing global estimate at satellite level
  - Class 4 model providing estimates at sub-system level
- No schedule risk methodology has been developed at this stage to size the potential schedule drifts but the cost risk assessment does include some provision for schedule slippages based on actual schedule growth as observed on past projects
- Future developments for schedule modeling will focus on defining standard schedule template according to mission types to further increase the relevance of the schedule estimates
- Credible and proven schedule estimating capabilities have been identified as a key factor to successfully federate project teams from both Agency and Industry sides around common schedule containment objectives

ESA Schedule Drivers in Estimating (1/3)

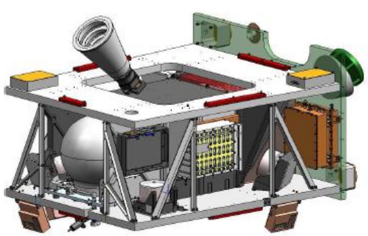


Payload Type

- ○ Instrument boxes on the outside, simple connections — Example: Proba 1, Cryosat, SMART-!
- ◉ Separate Payload Module with One or Multiple Instruments inside Platform or Payload Module body — Example: SMOS, MetOp, Herschel

Payload Complexity

- ○ Low Complexity — Example: Off the Shelf subsystems, Low Data Rate, Low number of simple instruments, Low gain antennas, ISS small Payloads
- ○ Moderate Complexity — Example: Minor modified subsystems, Low/medium data rate required, Low number of simple instruments, Low gain antennas, ISS small Payloads
- ○ Medium Complexity — Example: Modified subsystems, Medium data rate required, Medium/Standard DH performance required, Low or Medium gain antennas
- ○ High Complexity — Example: Major modified subsystems, Medium/High data rate required, Medium/Standard DH performance required, Medium/High gain antennas, several instruments on board
- ◉ Very High Complexity — Example: Newly developed subsystems, High data rate required, Complex instruments on board, Medium/High gain antennas



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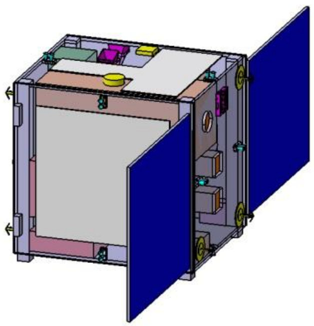
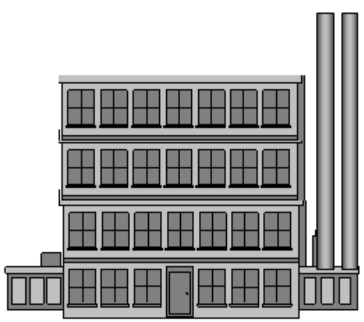
ESA Schedule Drivers in Estimating (2/3)



Platform Complexity

○ Low Complexity	Example: Off the Shelf subsystems status, low pointing accuracy, body mounted panels, low data rate, simple housekeeping, Cold Gas/ Monopropellant
○ Moderate Complexity	Example: Minor Modified subsystems, low pointing accuracy, body mounted/simple panels, low data rate, simple housekeeping, Cold Gas/ Monopropellant
○ Medium Complexity	Example: Modified subsystems, medium pointing accuracy, standard deployable solar arrays with standard cells, medium data rate, medium housekeeping, Mono or Bi propellant
○ High Complexity	Example: Major Modified subsystems, medium/high pointing accuracy, standard deployable solar arrays with standard cells, medium/high data rate, complex housekeeping, Mono or Bi propellant
◉ Very High Complexity	Example: Newly developed subsystem, high pointing accuracy, deployable solar arrays with special materials and cells, high data rate, complex housekeeping, Electric propulsion



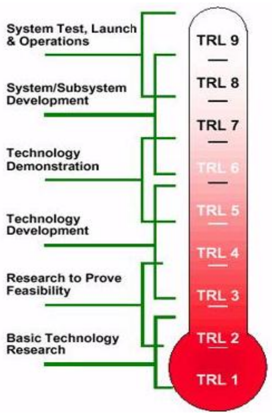
Industrial Set Up

○ Light	Example: Small/Medium Prime Contractor (SSTL, OHB), 1 layers core team (Prime level, S/C Prime is also Platform and P/L Prime)
○ Normal	Example: Large/Medium Prime Contractor (Astrium, Thales-Alenia,OHB), 2 layers core team (Prime, Platform level or P/L level, S/C Prime is also Platform or P/L Prime)
◉ Heavy	Example: Large Prime Contractor (Astrium, Thales-Alenia), 3 layers core team (Prime, Platform level, P/L level, S/C Prime different from Platform and P/L Primes)

ESA Schedule Drivers in Estimating (3/3)

Competition Situation

○ High	Example: Open competition, many feasible/valid/competitive Industrial solutions
◉ Normal/Standard	Example: Open competition, at least 2 valid (technically and for Geo return) competitors identified
○ Low Competition/Monopoly	Example: Direct negotiation, Identified Geo return or technical constraints that lead to Monopoly

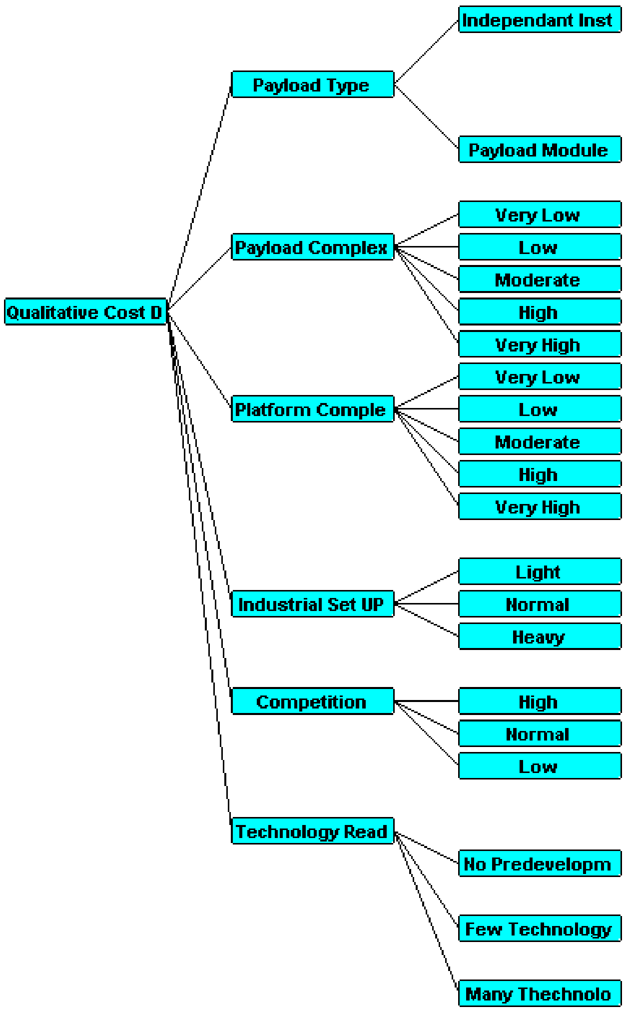


Technology Readiness Indicator

○ No Predevelopments	Example: TRL>=5 for all the subsystems/equipment.
○ Few Technology Developments	Example: Few subsystems/equipment with TRL<5, but not particularly critical technology roadmap. Maturity of technology assumed to be reached without significant delays.
◉ Many Technology Developments	Example1: Many subsystems/equipment with TRL<5; Example2: Few subsystems/equipment with TRL<5, but particularly critical technology roadmap. Maturity of technology assumed to be reached with significant delays and with ripple effect on the entire project schedule.

Note! Competition included as driver due to the additional module of the tool, estimating the cost

The AHP approach



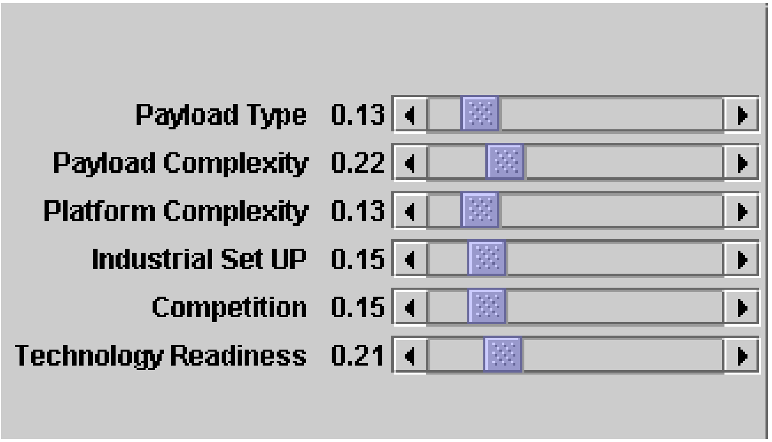
$$\left(A-\lambda_{\max} I\right)W = 0$$

A is the matrix of pairwise comparison

λ_{max} is the largest eigenvalue of A

W is the scale of weights

The scale of weights is obtained by solving for the principal eigenvector of the pair wise comparison matrix



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Summary

- Although ESA and NASA acquisition approaches are different, schedule seems to be more affected by other factors

- Larger average ESA mission development durations, for the data set, may be attributed to ESA missions being typically more organizationally complicated
  - For the Data Set, ESA's missions are typically larger, carry more instruments and more complicated as they require multiple Member State participation to ensure mission success
  - Additionally, ESA's risk avoidance posture may also contribute to longer schedules

- Similarities in ESA and NASA mission data set present some additional observations
  - For Planetary and small missions, the mission development durations and percent change between ESA and NASA are similar
  - This suggests that having a **clear, highly visible,** and **urgent** goal and/or milestone **shared by all stakeholders** is one way to maintain and manage to schedule

- Although it is unrealistic to expect that no schedule change will occur for complex space missions, using historical data as a guide could provide an estimate for a more robust initial schedule that could limit schedule change in the future
  - Collecting historical development durations and developing more robust schedule tools is a first step in helping to set robust initial schedule plans