Roman Space Telescope Lessons for the Future

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On behalf of
Roman Space Telescope Project

Habitable Worlds Observatory
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Many Thanks To…

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*In the following slides, the names have been changed to protect the innocent…*
While many individuals provided unique examples of lessons learned, they could generally be grouped under a set of common, high-level topics:
- Further grouped topics by relevance to project phase (pre-/post-implementation; general)

Uniform consensus among team is that 15 minutes is not enough time to cover these lessons:
- This presentation should be considered as an invitation to more in-depth engagement with project personnel on lessons, especially those of a more “sensitive” nature
- Then again, many of these will sound familiar…

Recommend a workshop or working group to develop and document the actionable steps we will take to incorporate lessons learned.

Lessons Learned 101: “We’d like to stop making the same mistakes over and over again so we can start making all new ones.”
Summary

• Pre-Implementation:
  – LL1: Build relationship with stakeholders / Engage the community
  – LL2: Invest in key enabling technologies to TRL 6 by PDR
  – *LL3: Be cautious of cost targets before PDR
  – LL4: Avoid requirements over-reach
  – LL5: Cost & schedule impacts due to desired operating temperature
  – LL6: Understand the impacts of hardware (Flight or GSE) and facility re-use
  – LL7: Start analysis & design early, including GSE and test configurations
  – *LL8: Include verification & validation details in early planning

• Implementation:
  – *LL9: Avoid requirements creep
  – LL10: Require forward-phased, consistent funding
  – LL11: Continuously reassess plans for work to go (“No plan survives contact with the enemy”)

• General:
  – LL12: NASA should lead Management, Systems, Modeling, and Integration
  – *LL13: Plan for differences in institutional culture and processes
  – *LL14: Have the right people in the right place at the right time
  – *LL15: Active control / compensation can reduce risk and increase robustness

*LL slides are provided for completeness, however will not be presented in detail in interest of time.
PRE-IMPLEMENTATION
LL1: Build Relationship with Stakeholders (1/2)

• **Stakeholder advocacy is critical when times are tough**
  – Want champions in the halls of HQ, Congress, science community, industry, and the public (see next slide)

• **A close partnership with HQ (SMD & APD) creates trust and facilitates communication that is crucial when issues arise**
  – The project needs to be able to openly & honestly communicate the cost and schedule risks associated with HQ- or externally-directed decisions
  – HQ needs to have enough insight into project to advocate on their behalf with Congress & public as well as hold project accountable

• **Make good use of reviews**
  – SRB* members are another set of advocates for the Project to HQ

*SRB: Standing Review Board
• Broadest possible community needs to be and feel involved and have a vested interest in the mission’s success
  – Maximize the use of town halls and open meetings; leverage branding and social media early

• Find balance in how the mission is “sold” to the community
  – Webb & Hubble were capability driven; Roman is science driven (e.g., survey)
    • Require different approaches to advertising to the community (“How will I use this observatory?”)
  – HWO is somewhere in between (exoplanet survey vs. general astro. capability)
    • Recognize the differing perspectives and balance the message to reach the whole community
    • Take action; create org structures to avoid stovepipes – we are one mission!

• Foster interaction between science & engineering teams
  – Both scientists and engineers need to understand
    • Science trades and how science drives technical and programmatic decisions
    • Where technical and programmatic “pain points” exist
    • Where investing time/budget matters, and when good enough is good enough
  – When issues arise, whole team needs to know to ask rather than assume, and know who to ask
• “Be rigorous and unflinchingly honest with yourselves about identifying key enabling technologies. Develop a robust plan to mature them – preferably gradually (alongside mission concepts), using modest annual investment over a long time. Don’t fudge this or believe the hype or assume disruptive breakthroughs.”

• “At this point (literally right now), HWO no longer has time for mission concepts and technology development to evolve in their own separate sandboxes. Every dollar and every brain needs to be assessing how to merge the two for the best achievable science reach in the 2030s.”
  – Corollary: mission concept developers and technology developers need to be directly involved with technology funding decisions. No stovepipes!
Cost targets established before PDR must strike a balance between committing to an acceptable cost and enabling the best possible science.

- Done well, effective trades and timely off-ramps (or occasionally on-ramps) enable incredible science for a given price point.
  - Combine with a commitment to forward phased, stable funding and executable program structure.
  - Done poorly, appropriators and the science community are both disappointed – and the broader community objectives are compromised for a decade or more.

We need to be careful about the language we use right now regarding the cost of the mission.

- Up and out: message commitment to deliver best possible science for a negotiated development (not lifecycle) cost; inflate $RY in the 2030s when development will occur.
- Down and in: message team commitment to great science at negotiated cost.
  - Use cost target to drive the tough, timely decisions and push creative thinking about technology maturation, off-ramps, and on-ramps (see LL4).
“Decide early what science objectives will be and then set a very high bar for adding anything later”
- E.g., Roman’s Level 1 & 2 requirements have not substantially changed since start of Phase A

Pre-implementation is the place to take risks
- Need to use this time to maximize science/dollar

But time (and money) is limited
- Need to set a deadline and “ruthlessly” assess what will be ready by that deadline and drop anything that won’t

Have science margin
- Be able to fall back to a mission that is still worth doing if certain technology doesn’t pan out
- Again, set deadlines for decisions and stick to them
Across the team, there are differing thoughts on how “cold” (~265 K) operating temperature fundamentally impacted cost, schedule, and risk, yet consensus opinion is that it did so significantly:

- Modifying inherited hardware to operate modestly colder-than originally designed
- Designing all new aft-optics system to work at colder temperatures
- Adapting “standard” processes for new cold development & test (e.g., new materials & process qualification for things as mundane as harness tie downs)
- New thermal cycling and strength tests
- Analysis and testing came with a heavy integrated modeling cost burden and substantial facility upgrades

“If science objectives can be achieved in other ways, room temperature optics have far less cost growth risk.”
LL6: Hardware (Flight or GSE*) and Facility Re-use

• If deciding to re-use hardware (Flight or GSE*), make every effort to use it exactly as originally intended (see LL5)
  – Old hardware may not match the documentation that comes with it, especially GSE for which documentation requirements are less stringent
  – Conversely inherited / re-used hardware can have advantages as it collapses the trade space and focuses the team on a specific design

• Facility upgrades carry large cost and schedule risk
  – Identify and start on them as early as possible
  – “Ground tests are extremely complicated and best designed-for-purpose”; simply showing you fit in the chamber is not enough
    • Roman TVAC tests have gone through numerous iterations right up to early this year
  – Pay attention to the mundane infrastructure (transportation, cranes, dollies, test flats, hexapods, etc.)
    • Can become critical path drivers very quickly (“My kingdom for a hexapod!”)

• Don’t neglect IT infrastructure!
  – Especially if tests will be performed in secure facilities – how do you get the data out?
  – Re-using old IT equipment and legacy software will require costly hardware and software upgrades

*GSE: Ground Support Equipment
• Develop Flight and GSE interfaces concurrently
  – Late discoveries of GSE-to-Flight hardware interference and GSE compatibility led to some significant test configuration changes (see LL6)

• Early investment in integrated modeling (IM) will more than pay for itself over the long run
  – Like JWST & Roman, HWO will be very dependent on analysis
  – Budget for an extensive IM effort with an engaged review board, and potentially even independent teams
  – Early investment in high-fidelity IM, skilled practitioners, and a capable manager to create a flexible and robust modeling architecture buys down the technical and programmatic risk of growth across the board

• Need a “deep bench”
  – Analyses are niche, so losing a single person during course of mission can have a big impact

• Don’t forget stray light!
  – It’s hard to model, next to impossible to test for, and almost certainly the thing you’re going to get wrong
*LL8: Include verification & validation *details* in early planning

- Simply saying a requirement will be verified by test, analysis, or both isn't enough
  - Need a verification roadmap with more detail in verification description as early as possible as they can have big differences in cost and drive facility needs

- Identify model validation tests early and protect them

- Requirements flow down, not up
  - When writing Level \( N \) requirements, think about what you need at Level \( N+1 \) and make sure you write the appropriate parent. If there isn't an appropriate parent, then do you really need that requirement?

- Every level of assembly should have documented, clear, traceable requirements flow down with associated verification approach
IMPLEMENTATION
In implementation, emphasis shifts to what is “good enough”
  – NO new requirements or capability at this phase

Again – define, document, and plan to use offramps and descopes that can be executed when “better” starts driving cost & schedule (see LL11)
LL10: Require forward-phased, consistent funding

- Roman has received forward-phased funding per its plan every year
  - Enables early, strategic investments that buy down risk later in development
  - Ensures steady, consistent progress and use of reserves to quickly mitigate challenges
  - Forward fund procurements and contracts to continue making progress throughout the year and mitigate impacts of “black swan” events (CRs, shutdowns, pandemics, etc.)

- Effective management of reserves is key
  - When early allocation of reserves is required, make sure it reduces risk of cost/schedule growth in the long term (see LL11) – not increasing baseline
LL11: Continuously reassess plans for work to go

• “No plan survives contact with the enemy”
  – Plans are essential, but cannot be blindly executed without reassessment
  – Programmatic and technical leadership needs to be constantly predicting long term performance and taking action to mitigate risks

• Immediate investment **now** can often shrink long-term cost and schedule growth **later**
  – Project management/leadership team needs direct control of significant moving parts to change courses (see LL12)

• “In Phase A, you're already out of time and money but just don't know it yet. Develop discipline early.”
ENTIRE LIFECYCLE
LL12: NASA as Lead

• NASA should serve as Management, Systems, Modeling, and Integration Lead
  – “This can’t be emphasized enough.”
  – “Early years of Webb, NPOESS epoch, lots of human flight programs are case studies of what happens when NASA follows the ‘smart buyer’ approach with even most capable industry partners.”
  – “Roman (will be) the first successful, cost-capped science flagship - use its example”
    • See also later years of JWST

• This also enables many of the other lessons learned as the project holds the required authority and has access to near real-time data needed to anticipate problems and respond quickly to mitigate impacts
“Standard Rules” for processes and procedures (e.g., GOLD Rules, GEVS*) vary between government & industry, vendor to vendor, and even Center to Center

- Need to be clear on what we expect to receive as a product
  - EITHER let the vendor follow their own processes and document and communicate associated risks at the highest level
  - OR prescribe exactly what we expect them to do and include additional costs in the program up front

- Have a strong leadership team in place early and for the long haul to ensure continuity and have long term vision to understand impacts of early decisions
  - Sometimes early decisions are made without sufficient documentation on rationale; when new team comes on later it can create a lot of churn to “re-litigate” those decisions

*LL13: Plan for differences in institutional culture and processes

*GEVS: Goddard Environment Verification Standard; GOLD: Goddard Open Learning Design
*LL14: Have the right people in the right place at the right time

• Rely on experience whenever possible and strong mentorship when it’s not

• Match strengths across team to the work that needs to be done
  – Requires being brutally honest about local strengths & weaknesses
  – Understand the cultural and process differences between partners (see LL13)

• Balance oversight with need to let partners work
  – Encourage direct engineer-to-engineer interaction rather than funnelling through a PoC
  – Oversight team needs complementary skillsets across disciplines
  – Have an on-site oversight person/team for time critical interactions
*LL15: Active control / compensation can reduce risk

- Roman OTA has shown good ability to place optics with traditional methods, but ability to use actuators to adjust for offsets/errors/changes in environment has been critical and significantly reduced risk/increased robustness.

- But actuators are difficult to manufacture and drive electronics are expensive.

- “A compensator would likely pay for itself IF it can save a handful of days on the project critical path. For example, an actuated optic may enable the project to reduce the complexity of a top-level optical test.”
QUESTIONS?