Final Report

of the
New Worlds Observer (NWO)
Technical Assessment Review (TAR)
Based primarily upon the Nov. 5-7, 2008 Review at NGST, Redondo Beach, CA
and subsequent communications
April 9, 2009

Introduction

The New Worlds Observer (NWO) Technical Assessment Review (TAR) panel was convened to provide an independent review of the feasibility of the NWO architecture. The goal given to the TAR from the NWO team is the following:

TAR Panel Charter:

> Provide an independent technical assessment of the feasibility of the New Worlds Observer mission architecture, key technologies, roadmap, and readiness. Deliver a final assessment report in a month that will be included as an appendix in the New Worlds Observer study report delivered to NASA Headquarters.

The TAR panel members were assembled from home institution experts who had no or very little involvement with NWO and have little to zero stake in its success. Due to funding constraints, the team was not able to obtain panel members from other institutions to make this a true Non-Advocate Review, but the intention was the same.

The TAR panel members are:

Name	Institution	Expertise
Dennis Andrucyk	NASA/GSFC	Chair
Eugene Waluschka	NASA/GSFC	Optics
Jesse Leitner	NASA/GSFC	Formation Flight
Caitlin Eubank	NASA/GSFC	Propulsion
Alphonso Stewart	NASA/GSFC	Mechanisms
Lloyd Purves	NASA/GSFC	Sys. Engineering
Steve Jordan	Ball Aerospace	SE/Program
David Pohl	NGST	Structures/SC
Marty Flannery	NGST	Optics
Ann Weichbrod	NGST	Power/SC
Mark Hickman	NASA/GRC	Program
Len Efron	Consultant	Orbits

The TAR panel was charged with confirming:

(a) science objectives are clearly understood and comprehensively defined;
(b) preliminary mission requirements are traceable to science objectives;
(c) the operations concept clearly supports achievement of science objectives;
(d) technology development plans and dependencies are understood;
(e) preliminary mission planning demonstrates technical and programmatic feasibility.

The bulk of the TAR activity took place at Northrop Grumman Space Technology's Space Park in Redondo Beach, from Nov. 5th to 7th 2008. Prior to this review, the TAR panel was sent a series of presentations. The agenda of the review was:

Day 1: Wednesday, November 5, 2008

08:00 – 08:15 am	Welcome, Introductions, and TAR Charter (Garrison)
08:15 – 09:00 am	NWO Mission Overview (Cash)
09:00 – 09:30 am	Science Overview and Goals (Turnbull)
09:30 – 09:45 am	BREAK (15 min.)
09:45 – 10:30 am	Mission Requirements (Oleas/Lakins)
10:30 – 11:15 am	Conceptual Design Overview (Lo)
11:15 – 11:30 am	WORKING LUNCH
11:30 – 12:15 pm	Starshade Shape Control (Glassman)
12:15 – 01:15 pm	Starshade Packaging and Deployment Approaches (Lo/Dailey)
01:15 – 01:30 pm	BREAK (15 min.)
01:30 – 02:15 pm	Orbit Design/Phasing (Richon/Williams)
02:15 – 03:15 pm	Trajectory Alignment Control (Noecker)
03:15 – 03:30 pm	BREAK (15 min.)
03:30 – 04:15 pm	Telescope & Instruments (Noecker)
04:15 – 04:45 pm	Starshade Spacecraft & Concept of Operations (Lo)
04:45 – 05:15 pm	Discussion, Issues, Questions, and Summary

Day 2: Thursday, November 6, 2008

08:30 – 09:30 am	Technology Assessment & Roadmap (Hyde/Polidan)
09:30 – 10:15 am	Mission Schedule, Cost, and Programmatics (Lakins/Garrison)
10:00 – 12:00 noon	Discussion and any necessary follow-up on presentations
12:00 – 01:00 pm	LUNCH (1 hr.)
01:00 – 05:00 pm	Panel meets to formulate preliminary conclusions

Day 3: Friday, November 7, 2008

4hr	Panel debriefs NWO team of preliminary findings

The presentation packages were made available to the TAR panel for further review, comment, and assisted in providing a thorough assessment of the NWO team progress to date.

The day after the presentations, the panel provided an interim report which is attached as Appendix A.

The team and the TAR panel held a follow-up telecon on Nov. 25th to discuss further suggestions and questions from the panel and to give the team a chance to respond to questions raised by the panel that could not be answered during the review.

TAR Assessment

Summary of TAR assessment

The general consensus of the TAR panel was that the NWO mission concept presented is at or well ahead of the expectations for a project at this stage of development. The team presentations met the goals for the review and addressed the promised topics. The interim report also provided some detailed suggestions which this final assessment will not include.

Key Positive Assessments

- The panel felt that NWO is a plausible mission with very interesting science. The mission concept was defined sufficiently to indicate that the design approach is tractable and responsive to requirements.
- The NWO team demonstrated that the mission planning can fulfill the science requirements. The technical and programmatic feasibility was outlined and was of sufficient detail for a concept-level study.
- The deployment of the starshade and the mechanical systems analysis was very advanced for this stage of a mission; it was deemed a PDR-level of analysis, sufficient to reassure the panel members that this tall pole has been extensively studied.
- The panel felt the presentations put emphasis on the appropriate aspects of NWO. Although it is clear that more work has been done than was presented, the presentations focused on the aspects that the panelists had the most questions about.
- The panel felt that the team was honest and open with their findings; there was no indication that the team was sweeping any large issues "under the rug".
- There are areas that have had little attention, such as the spacecraft specifics, for the most part, these are deemed to be straightforward in implementation and the IRT concurs with the NWO approach to focus on the significant engineering and science challenge areas.

Key Areas of Concern

- As acknowledged by the team, NWO does not have a detailed Verification and Validation plan; this was felt to be especially necessary for a mission of such complexity.
- Along with the V&V plan, the current technology roadmap needs to be more detailed so a clearer understanding of the steps to flight can be gained.
- The team needs to do a better job of gathering and, more specifically, showing the trades that were performed in order to show the depth of the work. The point design approach sometimes did not allow panel members to understand the rational for certain design choices.
- The team needs to develop clear descope options along with a risk analysis for each descope of the mission.
- The panel understood that the focus of the work to date was on the starshade, but felt that, at this point of the study, more discussion was needed on the design of the 4 m telescope, which is the most costly aspect of the mission.
- The panel created a detailed list of presentation-oriented recommendations (such as make sure to discuss NWO in the context of other similar missions) which are included in the appendix.
- The operations management structure was not clear and a single authority for day to day

decision making must be established.
- Achieving the coordinated dual spacecraft obits and alignment is not a trivial and requires further analysis.

Panel Recommendations

- Since general astrophysics is ~70% of the telescope and mission time, the team needs to define the top general astrophysics projects that NWO will accomplish, in a manner similar to the Hubble Key projects.
- The general astrophysics community must be engaged in these key projects; perhaps the team can hold an NWO science conference.
- While the design of the passive starshade-control system that was shown was deemed sufficiently in depth, the panel recommends the development of a back up, active control design for starshade edges.
- The team should do further and more detailed research into the JWST design of both the telescope and the sunshade to determine what commonalities can be leveraged between the two programs.
- Identify a process to coordinate the two NWO spacecraft scheduling through a single authority. This would include allowing for scheduling targets of opportunity.
- Further develop and optimize the flight dynamics scenario(s) for NWO, differentiating between orbit determination and orbit/attitude control.

Conclusion

The review was structured in a formal fashion such that the goals and materials to be covered were all given ample time. The tone of the review was cordial in nature, enough so that there was ample, open dialogue between the TAR panel and the NWO team. As engineers/scientists will often do, discussions took a deep dive into individual technical trades where concepts were explored, rationale discussed, and decisions revisited that would be typically resolved much later in a Project Life Cycle.

The TAR panel concurred with the NWO Team philosophy to spend the majority of their time on the most technically challenging areas such as the Star Shade, its deployment, geometry, materials, etc., and less time on less challenging aspects of the mission.

The NWO Team was very prepared for the review, showed unending energy and enthusiasm, and was very open. During subsequent telecons/email exchanges they have demonstrated those same positive traits. The NWO Team is to be commended for their progress to date.

Appendix A: NWO Interim Report

Reviewer/Discipline: Dennis J Andrucyk/Chair Date/Rev: Nov 7, 2008/rev b

Report Out

of the

New Worlds Observer (NWO)

Technical Assessment Review (TAR)

Based upon the Nov. 5-7, 2008 Review at NGST, Redondo Beach, CA

TAR Panel Charter:

Provide an independent technical assessment of the feasibility of the New Worlds Observer mission architecture, key technologies, roadmap, and readiness. Deliver a final assessment report in a month that will be included as an appendix in the New Worlds Observer study report delivered to NASA Headquarters.

TAR Panel Members:

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Goals:

Confirm that (a) science objectives are clearly understood and comprehensively defined, (b) preliminary mission requirements are traceable to science objectives, (c) the operations concept clearly supports achievement of science objectives, (d) technology development plans and dependencies are understood and (e) preliminary mission planning demonstrates technical and programmatic feasibility.

Scope of Review:

The NWO Team will provide a complete description of the conceptual mission design, by means of block diagrams depicting system interfaces with external supporting systems as well as depicting interfaces between independent system elements. Preliminary modeling and analysis results should be presented in order to illustrate feasibility of achieving science objectives.

Criteria for TAR Successful Completion

Mission Requirements:

a. Mission objectives are defined completely and are realistically achievable within the context of the mission.
b. Mission level assumptions and constraints are defined and quantified.
c. Preliminary interface requirements with external systems are defined.
d. A plan for usage of units of measurement is defined in accord with agency requirements.
e. Reasonable interface requirements have been identified between independent system elements.
f. Results of mission level requirements trades completed to date are documented and include rationale for selected alternatives. On-going or needed future trade studies are identified with potential impacts understood and able to be accommodated. Selection criteria are defined for evaluating the results of such studies.

Mission Operations:

a. A mission operations concept has been defined that fulfills science objectives.
b. Launch and early orbit considerations have been conceptually identified.

Conceptual Design:

a. A conceptual system configuration is defined with sufficient understanding to indicate that a design approach exists that is tractable and responsive to requirements.
b. Preliminary modeling and analysis results (e.g.: performance, reliability, etc.) are available and have been considered in the conceptual system configuration.
c. Ongoing or future design related trade studies are identified and potential impact of results is understood. Selection rationale for evaluating trade results is defined.
d. Technology dependencies are defined and understood. Timely availability is reasonable. Alternative approaches for critical dependencies have been determined.
e. Utilization of major heritage elements has been identified. Adaptation for the current application appears tractable.
f. Adequate design margins for critical resources (mass, power, data rate, etc.) are estimated.

Safety and Risk Management:

a. Initial hazard identification and control methods have been determined.

Implementation Planning:

a. Program flow has been preliminarily defined to allow estimates for required hardware quantities.

Programmatics: (costing elements will not be reviewed)

a. Roles, responsibilities, and interfaces between all participating institutions are preliminarily defined.

Assessment

Executive Summary:
The TAR consisted of two days of briefing material

- Dialogue focused primarily on science and meeting the science requirement(s)
- The review team learned that the vast majority of engineering required for NWO is simple. The concept of it's "just engineering" shall forever be memorialized
- We did not collectively discuss the process for incorporating the TAR Team feedback
    - Responses to feedback from NWO
    - Timeline

TAR introduced several new technical terms

- Mega meter (Mm)
- Triode
- Plasma Polaritons

The NWO team

- Provided a high level conceptual design
- Focused on the more complex elements of the architecture. Leaving "just engineering" for later. An adequate approach for now but the engineering must be addressed soon (for example).
    - The placement of the thrusters and star tracker near the solar arrays is viewed as problematic from an impingement standpoint for the thrusters. It was also noted that the GNC system performance would be greatly enhanced if the star trackers were mounted on/near the optical bench.
- A good deal of design and modeling of key parameters for one design approach of the StarShade has been undertaken.
    - Several varieties of shapes/petal configurations were ***very briefly*** discussed
    - One design has been modeled to the point of incorporating specific design characteristics, materials, deployment mechanisms, reliability, thermal performance, mission impacts to space debris impacts, and other factors.

TAR was left with the impression that building a 4m optic (mono or segmented) is straightforward. This needs further definition.

The flight dynamics

- Getting the two spacecraft to their respective orbits at L2 is not particularly challenging and minimal efforts have been expended here.
- Greater effort has been put into the GNC of the StarShade spacecraft during mission operations. Use of a Xenon Solar Electric Propulsion system to minimize consumables during transit from one observation opportunity to another with a separate bi-propellant system for more precise station keeping is proposed (more on that later).
- Further definition of the conops in this area would be helpful

Descope options have not been fully explored or not fully presented

Have a graphics artist/editor work the charts to take care of color conflicts, consistent formats

Scope of the Review:
The NWO team fully and appropriately addressed the intended scope of the review as defined.

Review of Each Element:
Goals: Confirm that:
(a) Science objectives are clearly understood and comprehensively defined

- In the area of General Astrophysics (GA), define science themes and key projects, in priority order, with specific metrics (note: GA represents a significant amount of observation time)
- Emphasize the GA at the UV end of the spectrum for the 4m monolithic, possibly off axis
- Define a worthwhile minimum exo-planet mission (science floor) with sufficiently high probability of success – what are the likely criteria that satisfies the DS - should the pale blue dot be elusive
- From Web's briefing, Chart 3+, "Themes from 2006 Astrophysics Roadmap", how does NWO compare to "the competition"? Formally address strengths of NWO vs. other approaches – e.g. coronagraph
- Address the impact of the next 10 years of expected exo-planet discoveries – e.g. Kepler
- Address in more depth the GA and exo-planet science return as compared to aperture size/cost
- What is the science rationale for a telescope alone if the StarShade isn't there (for whatever reason)
    - What are the science impacts of a partial deployment of the StarShade
        - Ranging from a single petal failed deployment to a total StarShade failure
        - What is the minimum science deployment for the StarShade?

(b) Preliminary mission requirements are traceable to science objectives

- The team is postulating specific instruments for the observatory vs. identifying generic instrument types and resource allocations (recommending the latter)
- The team needs formally identify and assign a Lead/Mission Systems Engineer
    - Someone to work across the end-to-end system engineering formulation
    - Systems engineering appears to be distributed

(c) The operations concept clearly supports achievement of science objectives

- Present additional detail on target acquisition/timing (traveling salesman problem)
    - Technical/performance/operational issues will affect the timing/sequencing/anomaly resolution/rescheduling (a good deal of verbal exchange, but needs to be expanded/clarified on the charts)
- What about servicing??? Again, there was a good deal of verbal exchange, but needs to be expanded/clarified on the charts.
- Specifically mention the study for the propulsion type being used to get to L2 (including the drivers of time, trajectory, radiation, mass, launch vehicle……)

- Develop a year in the life of NWO in addition to the movie showing StarShade transitions
- Need a study/conops of what could/should be done in LEO vs. direct trajectory to L2
- Need discussions/story of what could happen if the deployment mechanisms hang up – what are the workarounds
- The Flight Dynamics/ACS/GNC division of responsibilities, requirements, etc. need to be further discussed (the only place they are shown on the same chart is on the Product Breakdown Structure – even then, ACS and GNC are assumed as being under the spacecraft(s))
    - At one point, attitude knowledge and control requirements were shown as being the same
    - Ensure the problem of alignment control is not overlooked
    - Address cross link communication requirements for multi spacecraft alignment control
- Need to address multi spacecraft DSN issues at the DSN (availability, simultaneous communication, commitment, capability/upgrades, etc.)
    - Document the downlink data rate requirements – including DSN
- How will NWO interface with other related programs/projects (including international systems) for sharing of data/observations – is this even applicable?

(d) Technology development plans and dependencies are understood
- Need a near field optical test in a vacuum of a representation of a full scale system – e.g. 2 petals
- The technology portfolio is targeted at the StarShade
    - Need to address the low TRL technology issues for the optics and fine guidance
- Does any technology require spaceflight validation – ala a precursor mission or otherwise?

(e) Preliminary mission planning demonstrates technical and programmatic feasibility.
- There was adequate information to demonstrate the correct amount of mission planning and technical feasibility
- Programmatic feasibility regarding cost and schedule weren't addressed enough to discuss
- Organizational structure/feasibility needs further discussion – PI Mode emphasis in current briefing vs. Facility Class mission

Mission Requirements:

a. Mission objectives are defined completely and are realistically achievable within the context of the mission.
- In general, yes for exo-planet but not for GA (see above)
- Define the exo-planet terms more precisely on charts – eta sub Earth, Habitable Zone (HZ), Completeness, Contrast and Suppression
- Classify and prioritize Maggie's List – does the mission hang on Maggie's List
- Further define revisit criteria/frequency

b. Mission level assumptions and constraints are defined and quantified.

- See above
- Space Environments??
    - Solar events, geotail snapback, comets,…
    - Micro Meteorites and Orbital Debris (MMOD)??

c. Preliminary interface requirements with external systems are defined.
- These were discussed
    - DSN, Launch Vehicle, TDRSS, ???

d. A plan for usage of units of measurement is defined in accord with agency requirements.
- The NPR specifies metric units

e. Reasonable interface requirements have been identified between independent system elements.
- No known independent elements

f. Results of mission level requirements trades completed to date are documented and include rationale for selected alternatives. On-going or needed future trade studies are identified with potential impacts understood and able to be accommodated. Selection criteria are defined for evaluating the results of such studies.
- Some yes, some no- see above comments on need for Lead/Mission/End-to-End Systems Engineer

Mission Operations:

a. A mission operations concept has been defined that fulfills science objectives.
- What is the operational staffing need?
- Costing will depend upon staffing
- Limited detail presented

b. Launch and early orbit considerations have been conceptually identified.
- Separate launches were discussed
- Deployments "conceptually" fully defined
- Provide a more detailed timeline for Launch & Early Operations

Conceptual Design:

a. A conceptual system configuration is defined with sufficient understanding to indicate that a design approach exists that is tractable and responsive to requirements.
- The review team feels that this is a plausible mission for interesting science

b. Preliminary modeling and analysis results (e.g.: performance, reliability, etc.) are available and have been considered in the conceptual system configuration.
- More needed but is adequate for this stage in the mission definition

c. Ongoing or future design related trade studies are identified and potential impact of results is understood. Selection rationale for evaluating trade results is defined.

- There should be further documentation of identified trades of tall poles including assumptions and results

d. Technology dependencies are defined and understood. Timely availability is reasonable. Alternative approaches for critical dependencies have been determined.
- Yes, for the technology tall poles but not all technologies are identified (or articulated)

e. Utilization of major heritage elements has been identified. Adaptation for the current application appears tractable.
- Need further justification to use heritage designs or equipment
    - e.g. use of an off-the-shelf Reaction Wheel

f. Adequate design margins for critical resources (mass, power, data rate, etc.) are estimated.
- Mass with margin was presented
- Power and data rate margins weren't remembered
- Science fuel margin can be used to enhance science but was not presented (but we understand this data exists)

g. Specific Questions or concerns regarding a science or engineering topic presented or expected to be presented.
- Relative navigation and formation control needs more detail
    - It warrants a stand alone portion of the briefing
- Is there a way to use the residual power on the StarShade while coasting (additional sensors, etc.)
- Are there any other uses for the StarShade after exhausting Maggie's List (assuming consumables were available)
- Would like a more detailed look into the placement of the Telescope components (thrusters, star trackers, etc.)… thruster impingement and glint into the trackers
- What is the justification for the selected propulsion systems?? This wasn't presented.
- Leave the specification of the on-board data bus until you're sure you know which one(s) will be used

Safety and Risk Management:
a. Initial hazard identification and control methods have been determined.
- None presented other than the StarShade and the Telescope collision not being credible

Implementation Planning:
a. Program flow has been preliminarily defined to allow estimates for required hardware quantities.
- Not there yet

Programmatics: (costing elements will not be reviewed)

a. Roles, responsibilities, and interfaces between all participating institutions are preliminarily defined.
   - So far, so good but need to review for Facility Class Mission

Appendix B: Summary of TAR Panel Recommendations

Comments/Suggestions by Panel Members
Compiled by Amy Lo

System Engineering Improvements

- Present data rates and information needed just for Exoplanet use, separate out GA requirements so people can see clearly what is the bottom line for Exoplanet searches.
- set a range for all tolerances, put in maximums and set points
- in requirements, need to incorporate environmental effects on the starshade
- identify top performance perturbing parameters
- need to define off-ramps for all technology development needs and descope options
- resolve conflicting s/c modes in different charts
- where is the science team located?
- need different management structure, not PI led
- develop I&T and V&V plan, specifically, prove optical properties of starshade, TAC, and deployment system
- have list of level 1 requirements
- need risk analysis

Presentation/Project Improvement

- Justify why we went so deep on certain issues, is it to validate cost, or maybe validate requirements?
- need to figure out how to address unknown unknowns
- do a better sales job of showing the robustness of the deployment design
- lots of questions on how the optical codes work, and validity thereof, need some justification of it, or a plan of how to validate these codes
- need contrast vs. suppression slide
- show robust operation: e.g. what happens when we lost a petal
- take all the single launch discussion out, just state we are doing dual launch, and keep a back up slide on single launch
- do a better job on highlighting the separation of the starshade from telescope, show the telescope can work on its own without the starshade
- need to define completeness
- need testbed pictures on the tech roadmap
- present more on trades, conops, descope options, panel needs to understand what science is lost at each descope point
- put NWO in context of other missions, both space and ground
- need to put up our list of "solvable but we haven't gotten around to it" problems, and show that we are not scared of them
- need to say some words about exo-zodi mapping and how this can be a scientific risk to all TPF, and how NWO can get around it, or how a precursor mission can get around it
- stress that this is important science

Specific Area Responsibilities

GSFC

- can the mission use a smaller launch vehicle and use the SEP to get to a higher orbit?
- what ground resource do we need, quantify and list
- touch base with DSN on requirements
- find out if we can use class b designation for NWO

NGST

- link mechanical tolerances to failure modes
- need to figure out how the NGST optics code works (have elevator speech ready)
- tip feature launch survival is a question
- what is the erosion due to RAM particles, and spacecraft charging?
- what is the redundancy on JMAPs and the rest of the TAC system
- show some work on the mission planner
- what is the time to reach steady state on the starshade

Ball

- propellant plume glow analysis is needed
- shadow sensors details needed early in the TAC presentation
- what is the erosion due to RAM particles, and spacecraft charging?
- figure out if starshade is warm enough to emit in the shadow sensor band
- how much automation is needed in the astrometric system
- what is the heritage of retro reflectors?
- what is the pointing stability requirement on the telescope
- resolve possible plume impingement on the telescope spacecraft
- resolve potential solar panel glint issue to the star tracker
- TAC charts needs more on controls
- substantiate monolithic vs. segmented mirror choice

Panel Outbrief Notes

- need to show our decision process and trades
- panel not convinced building a 4 m telescope is easy
- since GA is 70% of the time, define some NWO key projects like Hubble did
- figure out if there is a way for global collaboration
- garner community interest by getting them involved in the GA, hold a science NWO conference
- look more deeply at heritage use, i.e. make sure when we cite a heritage, that it's really a heritage and not the old thing used in a totally new way