Section K: Launch Vehicles
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Introduction

We have analyzed both Delta IV and Atlas V Launch Vehicles that will accommodate the launch of both our NWO spacecraft. We have studied launching both spacecraft in a single launch (stacked configuration) and launching each spacecraft in a single launch vehicle. The configurations that were studied were the Atlas V 501, 511, 521, 531, 541 and 551 as well as the Delta IV Medium Plus (5, 2), (5,4) and the Delta IV Heavy Launch vehicles as illustrated in Figure K.1. The Delta IV Heavy Launch Vehicle was evaluated for the dual manifest configuration, where both the Science Telescope and the Starshade spacecraft are stacked inside the fairing.

Both NWO spacecraft designs are both 5-meter class spacecraft, compatible with the Atlas V and Delta IV 5-meter fairings.

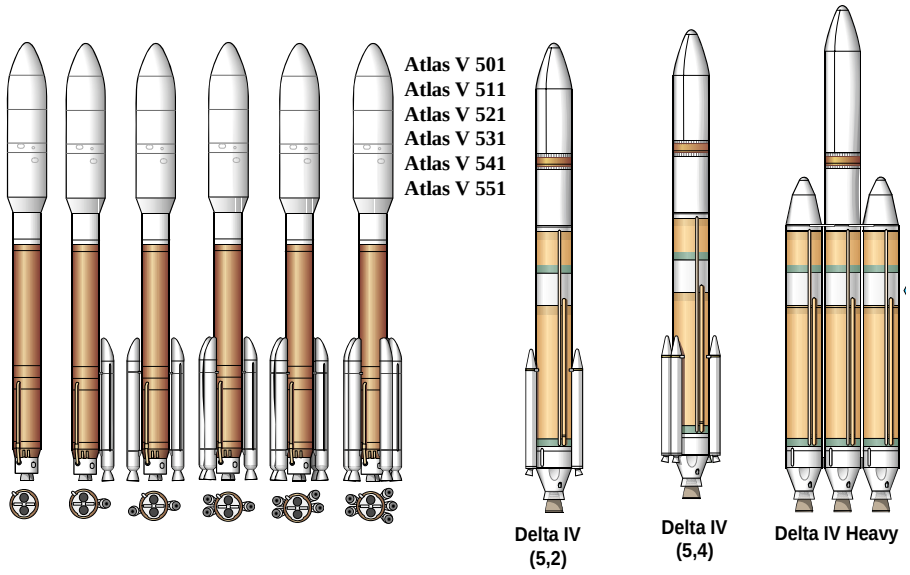

Figure K.1: Launch Vehicles

Analysis and Results of Trade Study

A trade study was performed to determine the launch costs and mass margins of the two NWO Spacecraft: Science Telescope and Starshade launched in two separate launches versus a single launch (stacked configuration). The other objective of the trade study was to determine if the costs of the launch vehicles outweigh the benefit of the mass margins and vice versa.
Launch Vehicle lift capability for all the Launch Vehicles specified above is listed in Table K.1. All values listed in Table K.1 are 3-sigma. We have selected an EELV

launch profile for high energy C3 (km^2/sec^2) of - 0.7 to - 0.6 ranges. The Lift Capability values listed in Table K.1 includes a NASA reserve (2% holdback) against the launch vehicle. The Atlas LVs utilize a Type B2 Payload Adapter and a C2 Spacer. The Delta IV Launch vehicles utilize the 1194-5 Payload Adapter.

Table K.1: Launch Vehicle Lift Capability

Launch Vehicles	Interplanetary Transfer Orbit, Escape Orbit perigee altitude: 185 km, C3 = -0.6 km^2/s^2 (kg)	Interplanetary Transfer Orbit, Escape Orbit perigee altitude: 185 km, C3 = -0.7 km^2/s^2 (kg)
Atlas V 501	2715	2720
Atlas V 511	3810	3815
Atlas V 521	4595	4605
Atlas V 531	5270	5275
Atlas V 541	5885	5895
Atlas V 551	6400	6410
Delta IV M+ (5,2)	3257	3270
Delta IV M+ (5,4)	4640	4650
Delta IV Heavy	9395	9410

Our current NWO Spacecraft design masses include a 30% margin to comply with the NASA Gold Rule GSFC–STD-1000 for Pre-Phase A. The current spacecraft total launch masses with margin for both Science Telescope and Starshade Spacecraft are listed in Tables K.2 and K.3. The Starshade and Telescope Spacecraft Dry Mass include a 30% margin. No additional propellant margin has been held in tables because propellant calculations are based on conservative Delta-V values.

Table K.2: Telescope Spacecraft Mass

STS Wet & Launch Mass				
	CBE Estimate (Kg)	**% Total Wet Mass**	**Contin-gency**	**Allocation (Kg)**
Spacecraft Dry Mass	4077	90%	30%	5300
Propellant Mass	448	10%		448
Spacecraft Wet Mass	**4525**	**100%**	**27%**	**5748**
Payload Adapter Fairing (PAF)	114		5%	120
Separation System	49		5%	51
Total Launch Mass	**4688**		**26%**	**5919**

Table K.3: Starshade Spacecraft Mass

Starshade Spacecraft Wet Mass				
	CBE Estimate (Kg)	**% Total Wet Mass**	**Contin-gency**	**Allocation (Kg)**
Starshade S/C Dry Mass	**2710**	**62%**	**30%**	**3523**
Propellant Mass - Xenon	**1220**	28%		**1220**
Propellant Mass - Biprop	**476**	418%		**476**
Starshade S/C Wet Mass	**4407**	**89%**	**18%**	**5220**
Payload Adapter Fairing (PAF)	114		**5%**	120
Separation System	49		**5%**	51
Total Launch Mass	**4570**		**18%**	**5391**

For separate launches, based on the lift capability defined in Table K.1, our NWO design has positive launch mass margin on an Atlas V 531, Atlas 541 and Atlas V 551 for the Starshade Spacecraft and on an Atlas V 531, Atlas 541 and Atlas V 551 for the Science Telescope as listed in Table K.4. For the Starshade Spacecraft we have a positive margin of 38.2% using the Atlas V 551; 26.9% using the Atlas V 541 and 13.5% using the Atlas V 531. For the Science Telescope Spacecraft we have a positive margin of 34.7% using the Atlas V 551; 23.7% using the Atlas V 541 and 10.6% using the Atlas V 531. In addition, Table K.4 includes cost information associated with each of the Launch Vehicles. The Atlas V 531 would be least expensive: $170M per launch, versus the Atlas V 541: $180M per launch and the Atlas V 551 which is the most expensive: $190M per launch. The cost of launching in the Delta IV Heavy is $265M.

The Delta IV Medium Plus (5,2) launch vehicles will not meet the mission launch vehicle performance restrictions neither for the Science Telescope nor the Starshade spacecraft. The Delta IV Medium Plus (5,4) provides a 1.5% positive margin to launch the Starshade Spacecraft only, however the Telescope Spacecraft cannot be launched in this LV. Furthermore, Atlas V 501, 511 or 521 will not meet the mission launch vehicle performance restrictions for any of the two NWO spacecraft. Spacecraft designs mass margins relative to the selected vehicles for separate single launch configurations are provided in Table K.4.

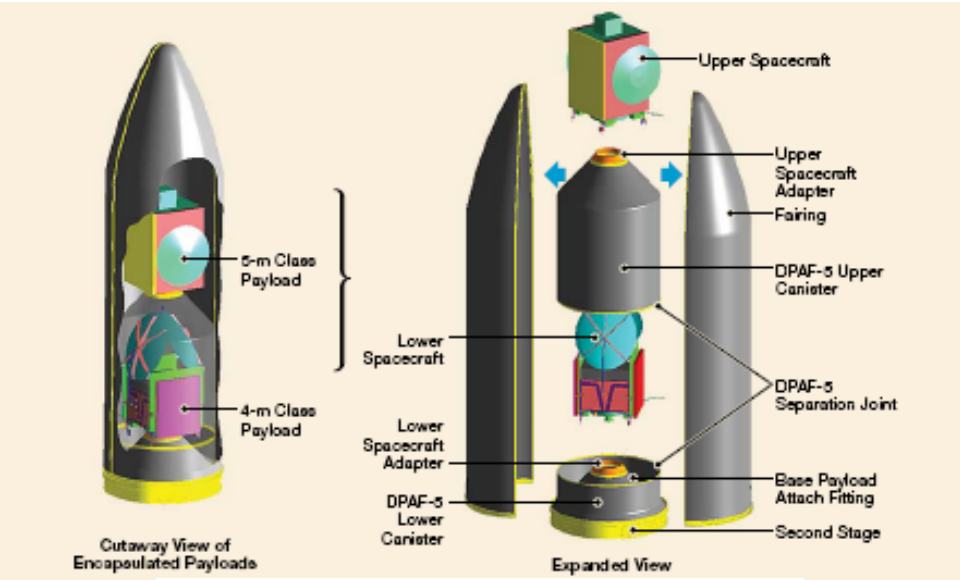

Figure K.2: Delta IV Heavy LV Fairing Limitations

We selected the two single launches in the Atlas 531, 541 or 551 with the margins mentioned in Table K.4 over launching one Delta IV Heavy Launch Vehicle with both spacecraft in the stacked configuration. This selection reduces development risk, providing spacecraft design closure without extraordinary efforts expended on mass reduction trades, thus enabling schedule protection. For dual manifest, single launch (stacked configuration), the Delta IV Heavy will not meet the mission launch vehicle performance restrictions to launch both NWO Spacecraft. The Delta IV Heavy launch limits the lower spacecraft to a 4-meter class Spacecraft. Based on the Payload Planner's Guide, the current Delta IV DPAF design has an internal structure (canister) which limits the lower spacecraft to ~4-m class spacecraft, as illustrated in Figure K.2. The DPAF design utilized to stack both spacecraft incurs more mass than what is accounted for in the Launch Vehicle Lift Capability table K.1. The estimated mass for the canister is approximately 1000 kg, which would reduce the lift capability significantly. However, the Delta IV Heavy Launch Vehicle could be used to launch the Starshade Spacecraft at the top and a non-NWO 4-meter class mission spacecraft payload as the lower spacecraft with the current canister design. The 4-meter class payload would have to be less than 3600 kg approximately. Such combination may provide positive launch mass margin.

Table K.3: Launch Vehicle Cost Information and Launch Mass Margins

Launch Vehicle	**Cost of Launch Vehicle ($Millions)**	Lift Capability (Interplanetary Transfer Orbit, Escape Orbit Perigee Altitude: 185 km, C3 = -0.6 Km^2/sec^2	Lift Capability Minus Penalty for Payload Adapter/Separation System	Total Starshade Spacecraft Launch Mass Without Margin (kg)	Total Starshade Spacecraft Launch Mass With Margin (kg)	Total Launch Vehicle Performance Mass Against **Starshade Spacecraft** Launch Mass Margin (%)	Total Science Telescope Launch Mass Without Margin (kg)	Total Science Telescope Launch Mass With Margin (kg)	Total Launch Vehicle Performance Mass Against **Telescope** Launch Mass Margin (%)
Atlas V 501	140	2715	2630	4570	5391	-42.5	4688	5919	-43.9
Atlas V 511	150	3810	3725	4570	5391	-18.5	4688	5919	-20.5
Atlas V 521	160	4595	4510	4570	5391	-1.3	4688	5919	-3.8
Atlas V 531	170	5270	5185	4570	5391	13.5	4688	5919	10.6
Atlas V 541	180	5885	5800	4570	5391	26.9	4688	5919	23.7
Atlas V 551	190	6400	6315	4570	5391	38.2	4688	5919	34.7
Delta IV M+ (5,2)	150	3257	3257	4570	5391	-28.7	4688	5919	-30.5
Delta IV M+ (5,4)	170	4640	4640	4570	5391	1.5	4688	5919	-1.0
Delta IV Heavy	265	9395	8395	9258	11310	-9.3	9258	11310	-9.3

Launch Vehicle Fairing Envelopes

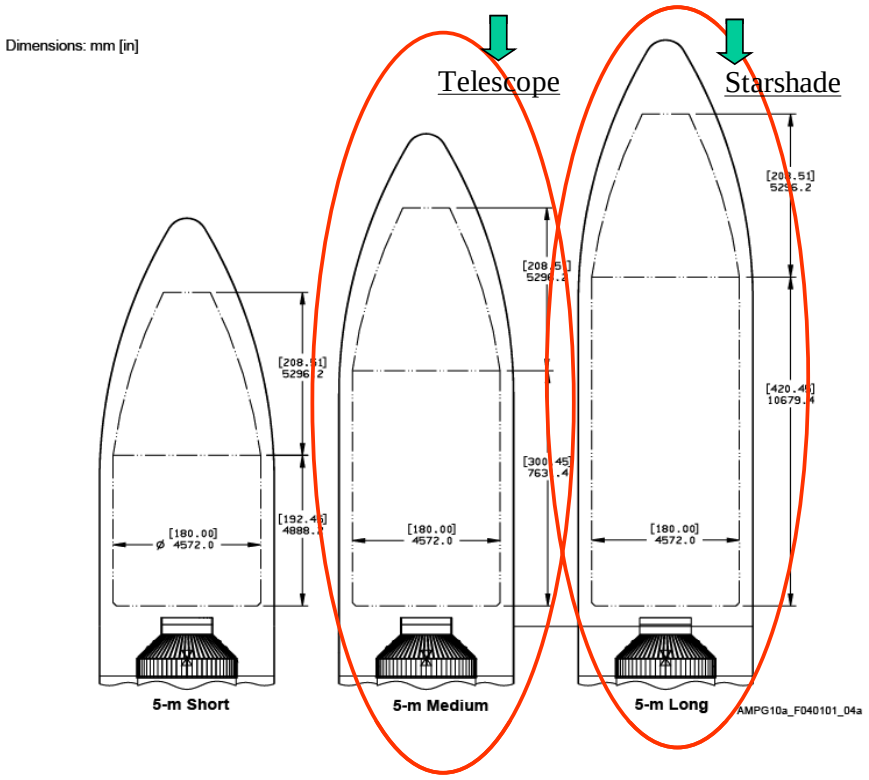

Figure K.3: Atlas V 5-meter Long Fairing Envelope

Figure K.3 illustrates the Atlas V 5-meter fairings. The Long fairing is used for the Starshade Spacecraft, whereas the Medium fairing is used for the Science Telescope Spacecraft.

Launch to Final Orbit Mission Analysis and Mission Profile

Our mission analysis and profile, incorporating single EELV launches and multi-burn transfer, provides the lowest cost, lowest risk approach that meets all mission design requirements with margin. We have selected an EELV launch profile for a high energy C3 (km^2/sec^2) of - 0.7 to - 0.6 ranges, and with a maximum 72 (TBR) minute eclipse constraint, to provide a 2-hour (TBR) launch window each day of the year.

Our current baseline for the two launches of the NWO Spacecraft take place six months apart from each other with the Telescope to be launched first. The Starshade Spacecraft follows the launch of the Telescope Spacecraft six months later to accommodate phasing orbit with the Telescope. The period of revolution of the L2 Orbit is six months.

We have also analyzed the costs associated with launching the Starshade spacecraft earlier than six months after the Telescope is launched. If second satellite is launched two weeks later, LV processing which normally takes a month could conceivably occur

with proper planning and support, assuming no weather delays occur. If second launch occurs two weeks later, additional costs would likely be needed for added crew, double and weekend shifts, added/customized GSE to speed processing. Pursuing a much faster turn-around times (less than two weeks) would significantly increase risk and cost. A cost estimate for a three-week processing turn-around is $2-5M versus for a two-week processing which is $5-8M. As far as a launch window three-week or four-week launch window for second launch may be possible but that some increase in LV performance may be needed to match arrival times. There is also another constraint in launch window which has to be considered. Ten days out of every month, launch will not be allowed since the Moon is too close, approximately 400,000 km, which would cause a sling-shot effect. We also considered other aspects for the second launch to minimize cost and complexity. The Spacecraft Ground Support Equipment (GSE) and communications networks for both spacecraft should be as common as possible to minimize set up and checkout (e.g. the same spacecraft GSE in the PVAN should be used for both SC to the maximum extent possible.) Minimizing spacecraft closeout operations and the need for clean tents would speed the closeout activities prior to roll out from the VIF to the pad. The two launches would be planned as back-to-back integrated launch campaigns with the second launch on an expedited, non-standard schedule. A back-up launch campaign slot for the second launch may be reserved, for a fee, for Launch 1 + 6 months, if the second launch fails to lift off within an acceptable period. If successfully launched, the reserved slot can be released. LV pricing should include a standard launch campaign, and expedited campaign (offset by some possible synergisms), a reserved back-up slot, and a second repeat campaign if needed.

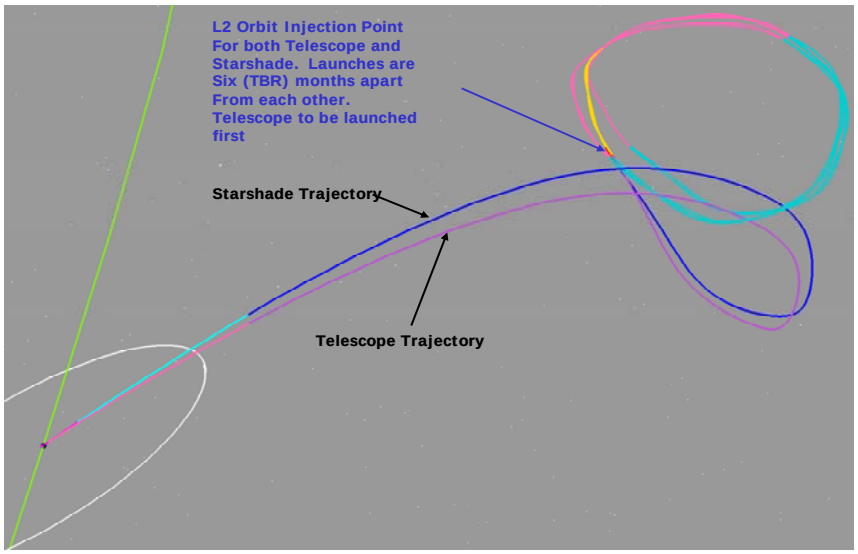

Figure K.4: Trajectory to L2 Orbit

Mission Control Center (MCC) monitors events after fairing jettison (approximately 5 minutes after liftoff) and prior to spacecraft separation (approximately 78 minutes after liftoff) via launch vehicle interleave and AFSCN resources. Existing TDRS White Sands Complex (WSC) and DSN resources provide tracking and telemetry support post separation. Within minutes of EELV separation, our spacecraft establishes sun pointed

attitude and deploys the solar arrays. Our orbit trajectory activities involve multiple burns to achieve final L2. Trajectory to L2 is illustrated in Figure K.4. All burns are performed in view of Ground stations. During coast periods, the spacecraft will be in an inertially fixed attitude with solar arrays facing the sun for maximum power, providing large thermal and energy balance margins.

Our mission profile supports GSFC Golden Rule 1.14 (avoid communication limitations and constraints) by aligning all critical events, such as burns, with available ground coverage and resources Additional details regarding early orbit operations, resources and responsibilities during the launch and launch processing phases are provided in the Operations Concept Sections, Appendix L.

Integration with Atlas V Launch System

We offer a flight proven integration process in support of NWO system integration with the assigned launch system and the major launch processing facilities at KSC and the Eastern Range (ER). Personnel experienced with these launch systems will develop the Launch Interface Requirements Document (LIRD), and then work closely with GSFC and KSC to manage the interfaces and support the development of a NWO LV ICD in conjunction with the United Launch Alliance (ULA).

NWO Spacecraft Design Compatibility with LV Environments

Our NWO spacecraft design will be compatible with both selected LVs launch environments. We use a systems engineering approach to develop mutually compatible interfaces between the spacecraft and selected launch systems. We will meet the environments of the selected LVs as defined in the Atlas V Mission Planners Guide (MPG), and the NASA Gold Rule. Our system integration process starts early in spacecraft development, allowing sufficient time and effort to: develop and allocate requirements; implement an integrated product development approach; optimally resolve interface issues; minimize cost, schedule, and design risks; develop ground processing flow to ensure availability of required facilities, MGSE, EGSE, transportation, and procedures compatible with ER safety requirements, comply with orbital debris requirements (NPR 8715.6 NASA Procedural Requirements for Limiting Orbital Debris - August 2007 and NASA-STD-8719.14 Process for Limiting Orbital Debris - August 2007) and to develop and implement a comprehensive verification plan and process.

Launch Site Integration and Test Program, Applicable Processes

We based our launch site integration and test program on our integration experience with the NASA and government spacecraft DSP, EOS, and TDRS 1-7. We provide a low-risk, cost-effective integration process for NWO, accomplished through early development of procedures and thorough checkouts and verifications of interfaces.

Government-Provided Resources, Facility Requirements, Mission Specific Services

Early identification of government-provided resources and facilities at the ER enables a low-risk spacecraft to launch vehicle integration by determining resource availability, identification and implementation of interfaces, and development of operations planning, and by allowing for schedule protection with sufficient time for potential conflict resolutions.