X-37B: A Mystery Spaceplane's Potential Capabilities and Mission

Trevor H. Johnson

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On 11 December 2012, the US Air Force launched the third Orbital Test Vehicle (OTV) flight under a shroud of secrecy and suspicion. Two previous missions, OTV-1 and OTV-2, have already logged flights of 225 and 468 days, respectively, and both returned to an autonomously controlled landing to Vandenberg AFB, marking the first time a spacecraft has returned to the Earth in such a manner since the Soviet *Buran* flew a robotic mission in 1988. While many aspects of the previous two and the current mission remain classified, publicly available information nonetheless reveals the X-37B as a state-of-the-art spaceplane. While it may not represent significant reduction in launch costs, it gives the US Air Force and the Intelligence Community (IC) a very flexible, reconfigurable asset whose payloads can be returned to secure locations for detailed physical analysis.

This research paper relies solely on publicly available information. The details of the X-37B configuration and mission are classified and as such this paper makes deductions and assumptions drawn from the author's aerospace and Air Force background.

2 NASA Development

As part of their Space Launch Initiative program, NASA began development of what would eventually lead to the Air Force's X-37B program in December 1998 (NASA, 2001). The Space Transportation System was by this time nearing 20 years of operational use, and NASA was continuing to search for an elusive solution to the problem of high space launch costs. Conceived as 120% scale version of the X-40, which had been successfully glide-tested in 1998, the X-37 as envisioned by NASA would be a testbed to develop technologies to reduce the cost of space access (NASA, 2001). Along with advancements in avionics, attitude control, and power systems, the X37 would test advanced thermal protection systems with improved durability and reduced maintenance costs.

In July 1999, NASA awarded a cost-sharing contract to Boeing to build the X-37. At the time the US Government and Boeing would split the $173 million cost 50/50, with the USAF supplying about $16 million of the government cost to cover technological development for advanced military spacecraft. NASA originally planned to complete autonomous recovery drop tests with an *Enterprise* analogous Approach and Landing Test Vehicle (ALTV) in 2002-2003 with launch of an orbital version in 2003 (Turner, 2003). Preliminary testing with glide testing with a modified X-40A proceeded as scheduled in 2001. These flights validated approach and landing guidance, navigation, and control technologies and flight operations control.

While the X-37 program seemed in position by 2002-2003 to overcome the kind of technological hurdles that stalled and ultimately led the to the cancellation of the X-33 Single Stage To Orbit (SSTO) project, in nonetheless encountered programatic hurdles that led NASA to abandon the project. With the *Columbia* accident in 2003 and the ensuing shift in NASA's human exploration priorities, spaceplane technologies likely fell out of favor as the Orion capsule was selected to replace the Shuttle orbiter. While a new contract with Boeing in November 2002 for $301 million secured funds for both an ALTV and orbital vehicle, plans to launch an operational X-37 were first pushed back to 2006, followed by transferral of the whole project to the Air Force in 2004 (Turner, Boeing).

3 Air Force Acquisition and Implementation

The X-40 precursor to the NASA's X-37 effort had been part of the Air Force's Space Maneuver Vehicle Program and represented a long progression of potential military space-planes. Air Force spaceplane aims began with the X-15 and Dyna-Soar programs of the 1960s and continued through the planned DoD Space Shuttle missions prior to the *Challenger* incident in 1986. With the operational employment of the X-37 in LEO, the Air Force finally obtained a spaceplane capability. Whether the X-37 under NASA represented a parallel or combined effort with the Air Force remains unclear-the Air Force certainly contributed $16M to the first X-37 contract.

What exactly does the Air Force need to accomplish with a spaceplane? Few space missions require the down-mass capability a spaceplane represents and even when a return to the Earth is required capsules have been a proven, and likely less expensive, solution for 50 years. Therefor the X-37B must represent a unique, in-demand capability that more conventional means cannot fulfill. Besides considering Air Force imposed requirements, analysis of the X-37B must also consider Joint military considerations and how this program fits into overarching DoD space operations.

Unlike NASA, which comprises an overarching oversight for civil space efforts, military space programs have no dedicated oversight apart from the Department of Defense itself. Apart from the Rapid Capabilities Office (RCO) which developed the X-37B, the Air Force oversees the Operationally Responsive Space Office (ORS Office) and partners with the illustrious National Reconnaissance Office (NRO), long known for its covert satellite operations. While Air Force Space Command operates the Eastern and Western ranges from which all major US launches take place, along with controlling many DoD space assets such as GPS, it works in conjunction rather than oversees these various DoD space operators.

3.1 Rapid Capabilities Office

When the X-37B project transferred from NASA to the Air Force in 2004, it was assigned to the newly established RCO, which is not a dedicated space program but rather a development agency to expediently promulgate new technologies needed by the joint (multi-service) combatant command structure. Their stated principles include close warfighter involvement in project development and timely accomplishment of the stated mission (RCO). Since the RCO reports to a board consisting of both high-ranking DoD and US Air Force officials, any project falling under the RCO would be held accountable to not only Air Force but broader DoD requirements.

Under the RCOs purview, DARPA concluding drop tests of the ALTV in 2006, with the first operational launch, OTV-1, occurring on April 22, 2010.

The RCO states publicly its purpose lies in development only: any programs extended programs would be transferred to an operational unit or suitable program management office. In the case of future X-37B operations, the likely operational units would be the ORS Office and the NRO.

3.2 The ORS and NRO

Undoubtably in response to the rapidly changing tactical environment US military and coalition forces have faced over the past decade, the ORS Office was formed to provide rapid response to urgent operational needs with on-demand space support (ORS, 2012). Unlike the secrecy clouding what perhaps may be the cutting edge payloads of the X-37B program, launches and general mission descriptions have been publicly released on the 4 completed launches to date. These payloads include dedicated ISR (intelligence, surveillance, and reconnaissance) for the CENTCOM AOR (Middle East theatre of operations) or other operationally imperative but otherwise established capabilities such as secure communications (ORS-1, 2012).

Created in secret on September 6th, 1961, the NRO has been charged since its inception in overseeing all space and overflight reconnaissance programs, making it one the major US intelligence agencies akin to the CIA and NSA. Like the three OTV launches, launches for the NRO are heavily shrouded in secrecy and usually subject to media blackout after the initial launch phase. In 2012 the NRO conducted 4 launches, each carried aboard ULA-built EELVs, including one Delta-IV Heavy (NRO, 2012). Such large, expensive, and highly classified payloads are routine for the NRO. Whether the NRO sees a benefit to a relatively inexpensive means to test forthcoming sensor technologies is certainly as classified as its daily operations and payloads but it is a reasonable conclusion. The X-37B is likely too small and limited a platform for many of sensors the NRO employs or is developing, but not all NRO missions require heavy lift capability or operation beyond LEO.

3.3 Impact of DoD Space Offices on X-37B program or future

Whatever the RCO and the US Air Force are trying to achieve with the X-37B program, it seems to bridge a gap in capabilities between those of Operationally Responsive Space and the strategic level intelligence gathering conducted by the NRO. The ability of the X-37B to return sensitive, classified payloads to secure locations on Earth for detailed analysis must be a boon for both the ORS Office and the NRO. With its reconfigurable payload bay, advanced power system, and extensive on-orbit maneuver capability, the X-37B has the ability to simultaneously conduct tests on experimental payloads while responding to operational requests through the ORS Office or other joint user. This is exactly what the ORS Office describes as it "Tier 1: Employ" initiative where existing space assets are redirected to meet urgent operational needs, except whereas other space systems would require sacrificing mission-life to accommodate the extreme case of orbit change, the X-37B is inherently designed to maneuver and vary its orbit.

3.4 Operational Design and Capabilities

3.4.1 NASA X-37

By mid-2003 NASA had completed it Mission Concept Review and outlined 47 technologies the OTV would employ and test. Most of these focused on improved, lighter and more durable Thermal Protection System (TPS) compared with the Space Shuttle along with guidance, navigation, and control to perform the X-37s on-orbit missions and autonomous landing recovery. Air Force involvement at this point was limited to funding for advanced solar array development and the X-40A glide testing. Combined these advancements also translated to significantly reduced inert mass, improving payload capacity and reducing launch costs. At this time NASA also stipulated the 270 mission-duration goal for on-orbit operations (Turner 2003).

While earlier program descriptions (NASA Marshall, 2001) had stipulated use of the AR-2/3 H_2O_2/JP-8 engine which reportedly carried over into the X-37B program (Grafwallner, 2004), the 2003 OTV planned use of two R-4D OMEs. Figure 1 details the NASA X-37 as it was conceived in 2003. Widely disseminated but unverified diagrams of the X-37B's configuration largely match Fig. 1 except for placing the JP-8 tank ahead of the payload bay and use of a single AR-2/3 main engine.

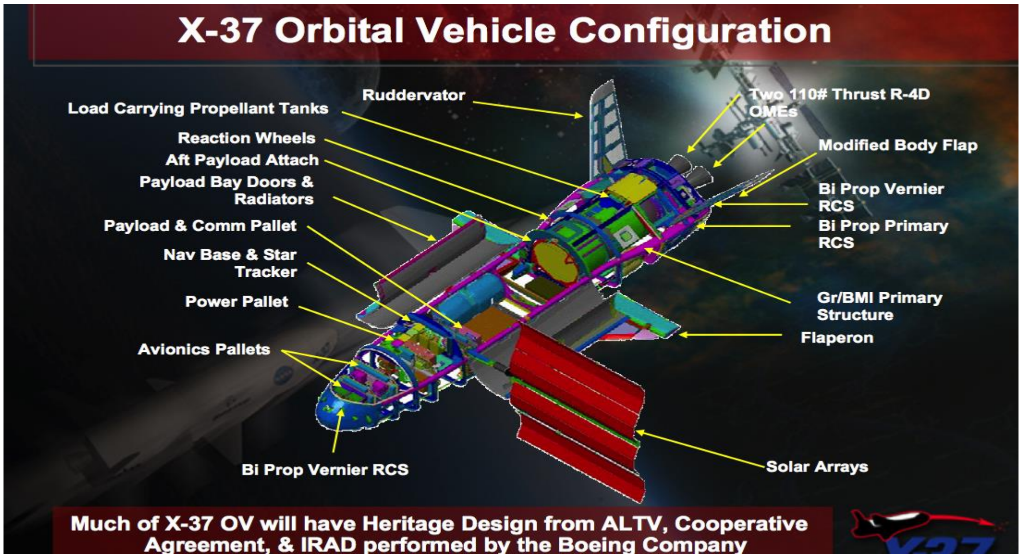
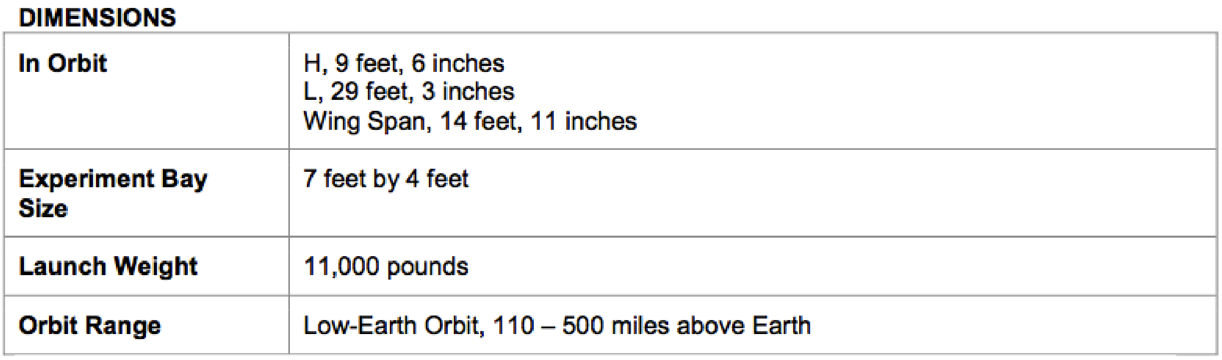


Figure 1: 2003 NASA design for X-37 (Courtesy NASA Marshall Space Flight Center 2003)

3.4.2 USAF X-37B

Unlike the NASA X-37 plans from 2003, the final USAF X-37B has been widely cited to use a single Rocketdyne AR-2/3 engine using high concentration (85% or higher) H_2O_2/JP-8 (kerosene) propellants.



DIMENSIONS

In Orbit	H, 9 feet, 6 inches L, 29 feet, 3 inches Wing Span, 14 feet, 11 inches
Experiment Bay Size	7 feet by 4 feet
Launch Weight	11,000 pounds
Orbit Range	Low-Earth Orbit, 110 – 500 miles above Earth

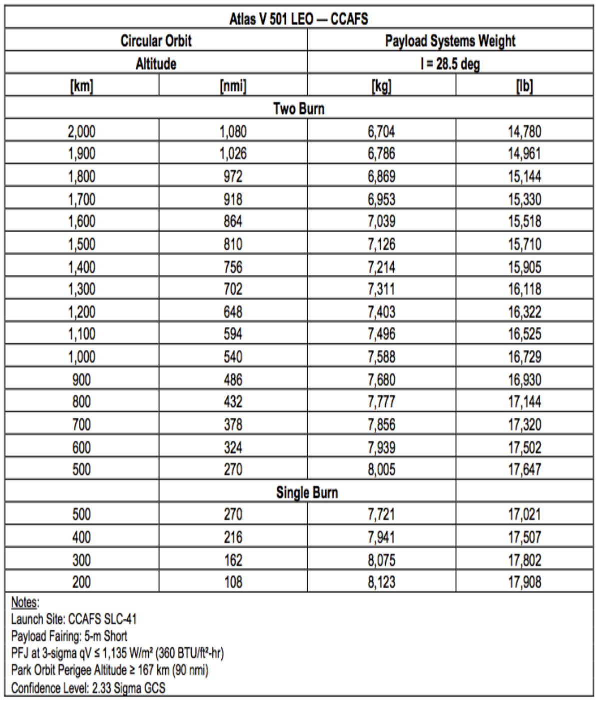
Table 1: X-37B Dimensions (Courtesy of Boeing)

A widely dispersed diagram of the Air Force X-37B featuring a single AR-2/3 engine and fuel and oxidizer split fore and aft of the payload bay, respectively was included in many news articles on the X-37B but could not be verified with official documents. In both the case of tanks split by the payload bay and both located aft of the payload bay the total propellant volume appears approximately the same as the payload bay volume, or conservatively ~$2m^3$.

Advanced thermal protection systems, avionics, and power systems likely carried over from the NASA program resulting in significant inert mass ratio drop and improved on-orbit/de-orbit/ground processing performance compared to the Space Shuttle orbiter.

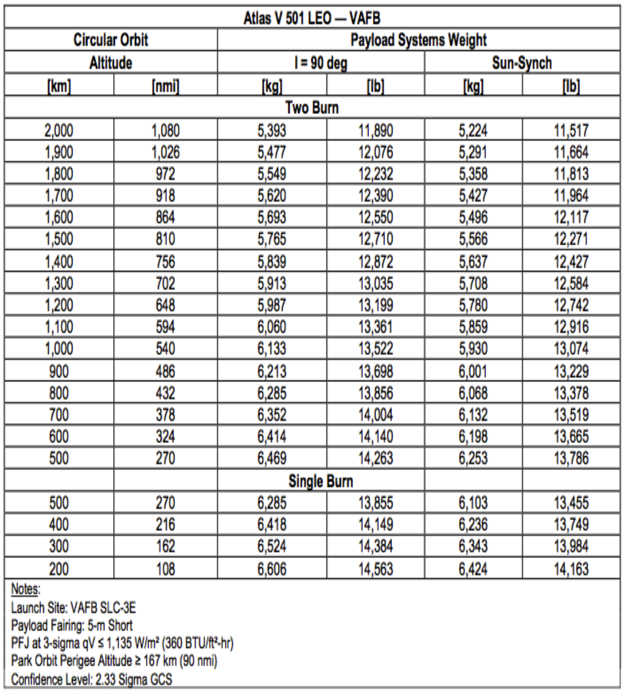
3.4.3 Launch Mass

While X-37 and X-37B documents report the orbital vehicle launch mass as 5000 kg, the Atlas V 501 (5 meter fairing, 0 solid rocket boosters, 1 engine Centaur) rocket used in all three OTV missions has the capability to lift heavier payloads to the designated 200-1000 km orbits. Assuming an intermediate altitude orbit of 500km, ULA calculates the Atlas V 501 capable of lifting the X-37B plus an additional 3000kg to a 28.5° orbit or in the case of a yet undemonstrated Vandenberg AFB launch 1250 kg beyond the stated vehicle launch mass (ULA, 2010). Increased inclination in the case of a launch from CCAFS would reduce the margin of excess capability but clearly in any case the Atlas V 501 can lift more than the publicly disclosed 5,000 kg (11,000 lbs) mass to LEO. Whether this is truly unused excess capacity or if this translates to additional payload or propellant on board the operational X-37B remains classified. However this demonstrates high flexibility to future X-37B missions. Lift capabilities for the 501 configuration to various orbits and altitudes are shown in tables 3 and 4.



Atlas V 501 LEO — CCAFS			
Circular Orbit		Payload Systems Weight	
Altitude		I = 28.5 deg	
[km]	[nmi]	[kg]	[lb]
Two Burn			
2,000	1,080	6,704	14,780
1,900	1,026	6,786	14,961
1,800	972	6,869	15,144
1,700	918	6,953	15,330
1,600	864	7,039	15,518
1,500	810	7,126	15,710
1,400	756	7,214	15,905
1,300	702	7,311	16,118
1,200	648	7,403	16,322
1,100	594	7,496	16,525
1,000	540	7,588	16,729
900	486	7,680	16,930
800	432	7,777	17,144
700	378	7,856	17,320
600	324	7,939	17,502
500	270	8,005	17,647
	Single Burn		
500	270	7,721	17,021
400	216	7,941	17,507
300	162	8,075	17,802
200	108	8,123	17,908

Notes:
Launch Site: CCAFS SLC-41
Payload Fairing: 5-m Short
PFJ at 3-sigma qV ≤ 1,135 W/m² (360 BTU/ft²-hr)
Park Orbit Perigee Altitude ≥ 167 km (90 nmi)
Confidence Level: 2.33 Sigma GCS



Atlas V 501 LEO — VAFB					
Circular Orbit		Payload Systems Weight			
Altitude		I = 90 deg		Sun-Synch	
[km]	[nmi]	[kg]	[lb]	[kg]	[lb]
Two Burn					
2,000	1,080	5,393	11,890	5,224	11,517
1,900	1,026	5,477	12,076	5,291	11,664
1,800	972	5,549	12,232	5,358	11,813
1,700	918	5,620	12,390	5,427	11,964
1,600	864	5,693	12,550	5,496	12,117
1,500	810	5,765	12,710	5,566	12,271
1,400	756	5,839	12,872	5,637	12,427
1,300	702	5,913	13,035	5,708	12,584
1,200	648	5,987	13,199	5,780	12,742
1,100	594	6,060	13,361	5,859	12,916
1,000	540	6,133	13,522	5,930	13,074
900	486	6,213	13,698	6,001	13,229
800	432	6,285	13,856	6,068	13,378
700	378	6,352	14,004	6,132	13,519
600	324	6,414	14,140	6,198	13,665
500	270	6,469	14,263	6,253	13,786
		Single Burn			
500	270	6,285	13,855	6,103	13,455
400	216	6,418	14,149	6,236	13,749
300	162	6,524	14,384	6,343	13,984
200	108	6,606	14,563	6,424	14,163

Notes:
Launch Site: VAFB SLC-3E
Payload Fairing: 5-m Short
PFJ at 3-sigma qV ≤ 1,135 W/m² (360 BTU/ft²-hr)
Park Orbit Perigee Altitude ≥ 167 km (90 nmi)
Confidence Level: 2.33 Sigma GCS

Tables 2 and 3: Atlas V 501 Lift Capability to 28.5° Polar, and Sun-Synchonous LEO (Courtesy ULA)

3.4.4 H_2O_2/JP-8 vs. NTO/MMH

A NASA roadmap study by McNeal Jr. and Anderson (1999) cited testing at

Stennis Space Center of a new H_2O_2/JP8 engine analogous to the AR 2-3 as having an impulse of approximately 280s. Depending on the mixture ratio used (2.55 to 6.0), the propellant bulk density ranged from about 1180-1300 kg/m^3. While this bulk density is somewhat better than N_2O_4/MMH (1202 kg/ m^3), the density specific impulse of a hydrogen peroxide/hydrocarbon system is about 360s compared to about 400s using N_2O_4/MMH. An additional joint ESA/NASA study by Grafwallner (2004) stated H_2O_2/kerosene engines offered improved compactness (supported by the bulk density data above) over existing systems and adhered to an 80/20 rule (80% of the performance, 20% of the cost).

As the X-37B is publicly designed to provide the USAF with a reliable, reusable space experimentation and evaluation platform, operational and maintenance costs must be weighed against the improved performance of toxic propellants such as N_2O_4/MMH. Consideration also must be given to the fact the X-37B is an Air Force, RCO program rather than a project of the NRO, whose multi-billion dollar payloads routinely require the utmost performance possible. The Titan's Nitrogen-Tetroxide (NTO)/Aerozine-50 engines were mainstay launchers for the NRO for decades, and the NRO remains one of the few users of the expensive Delta-IV Heavy launch vehicle (Graham, 2012). Judging from the contracts awarded during from the NASA X-37 program, the RCO X-37B budget is likely modest compared to even one NRO payload. Therefore the reduced long-term costs and ease of operating a H_2O_2/kerosene engine onboard the X-37B may outweigh the potential performance gains of a more traditional NTO/hydrazine based system.

Numerous public sources cite the X-37B as carrying over the NASA intent to use H_2O_2/JP-8 propellant, but one insider study cites the spaceplane as carrying higher performance hydrazine-type propellants (Covault, 2010). Certainly the HAZMAT equipment worn by recovery personnel suggests a toxic propellant load, although high concentration

Figure 2: X-37B de-fueling after OTV-2 (Courtesy of Boeing)

3.5 Likely Orbits and Operational History

NASA estimations and amateur astronomer observations have generally put past OTV missions at 35-45° inclination and 350-400km altitude orbits (National Space Science Data Center, 2012). While some news agencies have postulated on possible missions including observation of China's as yet unmanned space station, the mid-latitude inclination orbits from past OTV flights are much more suited to overflight of conflict areas in the Middle East, Africa, northern South America, and possibly some reference targets within the United States. Many US intelligence agencies along with military forces operating in the CENTCOM AOR are undoubtably interested in data from such areas.

3.5.1 OTV-1

Launched April 22, 2010, the first OTV flight completed a mission of 225 days and became the first US spacecraft to return to the Earth and land autonomously on a runway.

NASA had originally envisioned more conservative flight testing with an initial mission of only 21 days with a maximum intended stay on orbit of 270 days.

3.5.2 OTV-2

Following the success of the first mission, a second orbital X-37 vehicle was prepared and launched on May 5, 2011. This mission was again classified as to its purpose or duration, and remained quiet until it landed after a 468 day mission, far exceeding the originally specified 270 day mission duration.

3.6 Orbital Maneuvering

Although some uncertainty exists as to the exact performance of the main orbital maneuvering engine aboard the X-37B, conservative estimates of its orbital maneuvering capabilities can be run using an approximate I_{sp} of 280s (H_2O_2/kerosene propellants). Assuming the NASA-stipulated dry weight of 3,400 kg (7,500 lbs) and the Boeing quoted launch mass of 5000kg (11,000 lbs) are accurate, approximate ΔV values for set payload masses are tabulated below:

Payload Mass (kg)	Propellant Mass (kg)	ΔV Available (m/s)
500	1100	682
600	1000	612
700	900	545
800	800	478
900	700	414
1000	600	351
1100	500	289
Assumptions: Ideal rocket equation conditions, Isp=280s, initial mass = 5000 kg		

Table 4: ΔV available for X-37B orbital maneuvering at 5000 kg launch mass

The non-classified numbers may certainly bely the X-37Bs true capabilities, and knowing excess lift capability exists on the Atlas V 501 which carries the X-37B to orbit, the table below shows ΔV available assuming again a dry mass of 3,400 kg but a gross launch mass of 6000 kg, which would still allow both 28.5° and Polar/Sun-Synchronous LEO operations using the Atlas V 501. With an estimated total tank volume nearly equal to payload volume (2.0 vs 2.5 m^3), the maximum propellant using H_2O_2 / kerosene propellants with MR=6.0 and bulk density ~1300kg/ m^3 is ~2600kg. However this would mean carrying no payload so ΔV available was computed for a minimum payload of 500kg.

Payload Mass (kg)	Propellant Mass (kg)	ΔV Available (m/s)
500	2100	1182
600	2000	1113
700	1900	1045
800	1800	979
900	1700	914
1000	1600	851
1100	1500	789
1200	1400	729
1300	1300	670
1400	1200	612
1500	1100	556

Assumptions: Ideal rocket equation conditions, Isp=280s,
initial mass = 6000 kg dry mass = 3400 kg

Table 5: ΔV available for X-37B orbital maneuvering at 6000kg launch mass

Using $-\Delta H/4R_E \cdot V_{oa}$ to approximate the required de-orbit ΔV, the X-37B would need to reserve enough propellant for at least -90m/s deorbit burn, likely more due to its precise flight profile.

3.7 Possible Payloads

As an OTV has yet to be observed operating in the sun-synchronous orbit favored by visible light spectrum imagery, possible payloads aboard the X-37B include ELINT/SIGINT (electronic/signals intelligence). Various new sources have promulgated hypotheses about the OTV carrying weapons or other exotic cargo, but the X-37 was designed by NASA as a testbed, not a weapons platform, and it seems very unlikely the X-37B was substantially redesigned to accommodate the required avionics, communications, and other electronics for it to carry any sort of space weaponry. Advanced signals intelligence gathering equipment is a far more likely payload and one that would certainly entail the kind of classified operations thus far observed in the X-37B program.

4 Factors in deciding Program Continuation

Regardless of the previous success of the X-37B program in meeting its design criteria, the Air Force will need to justify the costs associated with long-term operational use of the X-37B and whether the system offers truly indispensable capabilities a non-recoverable satellite or capsule system could not provide.

4.1 Budgetary Considerations

Space systems such as the X-37B and the Atlas V 501 EELV launch vehicle which carries it to LEO fall under the Missile Procurement segment of the USAF budget.While this segment covers all missile, space booster and associated space systems from Air-to-Air missiles and ICBMs to EELV, over $2 billion out $5.5 billion total requested in the FY2013 budget would go to launch vehicles and classified programs (USAF, 2012). Individual EELV launch cost vary depending on configuration and launch location but on average the Air Force spends $420 million per launch. Launch costs and classified systems represent the two biggest outlays for the Missile Procurement budget, making the X-37B a very high profile, “big-ticket” item. While this likely means continued funding for OTV launches is a high priority for the USAF, it also makes the X-37B a target for budget cuts in an era where the military budget will likely still large reductions. However for the rest of FY13 classified funding is slated to increase to $1.01B from the $768M spent in FY12 so its possible the second X-37B may launch again within the current fiscal year10 before future drawbacks set in.

4.2 Shift to Capsule Systems

Following the *Columbia* disaster the space-plane ambitions of the 1990's (X-33, X-40, X-37), gradually gave way to a reintroduction of capsules with the advent of Orion and Dragon, which is currently America's only means of returning payloads from the International Space Station. The Space Shuttle ultimately proved to be not only horrendously complicated to maintain but also inherently unsafe, with considerable parts of the flight envelope where no redundant capacity existed. Capsules such a Dragon have already begun to show the huge cost savings associated with simplicity, as evidenced by Dragon parent company SpaceX receiving a multi-billion dollar contract to resupply the ISS and another several hundred million dollars to develop the capability to ferry crews (SpaceX). A DragonLab variant on the Dragon capsule is already filling launch orders to provide independent on-orbit laboratory space.

4.2.1 DragonLab as Commercial Off the Shelf (COTS)

Examining DragonLab reveals it shares many capabilities with the X-37B. While DragonLab lacks the open-sensor bay volume of X-37B, its otherwise unpressurized and pressurized available cargo room far exceed that of the OTV. Additionally it can haul up to 6,000kg of payload to orbit and handle up to 3,000kg of return or “down-mass” which is several times even the most optimistic guess at the X-37B's payload capacity (Space X). Undoubtably modifications could be made to accommodate specific mission requirements and while this would certainly increase mission cost DragonLab may still prove more cost-effective than the X-37B, as the baseline Falcon9/Dragon mission costs approximately $100M to the X-37B launch cost aboard an Atlas V of $300-400. Additionally, as a COTS purchase available on-hand from the commercial market, a Dragon capsule could be acquired only for those missions which require a down-mass capability. This would preclude requiring long-term storage of a specialized vehicle or wasteful invention of missions to justify operating costs.

5 Conclusion

The X-37B has proven during its first two missions and will likely prove again during the ongoing flight it possesses an unparallelled flexibility and testbed capability. The OTV missions bridge a gap between the rapidly developed, flexible, urgently required but limited capability of ORS assets and state-of-the-art capability but limited flexibility of strategic reconnaissance platforms operated by the NRO. No other system has ever offered the ability to conduct long-duration on-orbit testing of experimental sensor technology and return such payload to a secure location for extensive post-flight analysis.

As the X-37B program continues to mature from experimental to fully operational, its continued employment depends not only on the DoD's real need for its capabilities but also on whether the program can weather the current budget environment in Washington. US civil space applications have largely abandoned space-plane concepts for capsule based ones, and DragonLab or other forthcoming COTS equipment may make the advantage the X-37B provides over such systems hard to fiscally justify. So little publicly released data as to its exact purpose and cost makes prognosticating the future of the X-37B difficult at best.

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