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Revision A

Revision A

This revision updates the results in Sections 5 through 7 based on the attitudes in the July 22, 2009 Final ATL, including propellant and ΔV estimates for mission-specific maneuvers and attitude holds. A comment about the increased rate limit was added to the the Summary Section for the mated APU fuel dump scenario. A subsection was added in Section 3 to describe analysis to certify Orbiter attitude control during the N₂ vent for ATA replacement.

Summary

This memo provides a summary of the shuttle flight control parameters, I-Loads, control modes, jet tables, constraints, and recommendations for STS-128 mated Orbiter/ISS and unmated Orbiter Boom Sensor System (OBSS) operations. The DAP modes and constraints listed here are based on the STS-128 flight I-Loads defined in [1, 2].

The primary objective of the STS-128/17A mission is to deliver and retrieve cargo using the Multi-Purpose Logistics Module (MPLM) and to replace an Ammonia Tank Assembly (ATA). The MPLM will be installed onto the nadir Common Berthing Mechanism (CBM) port on Node2 using the Space Station Remote Manipulator System (SSRMS) early in the mission. Then, various items will be taken from or placed into the MPLM before it is returned to the Orbiter payload bay before undocking.

Visiting Vehicles and Mass Properties Due to variability in the launch schedules, there is uncertainty regarding which vehicles will be docked at the nadir DC1 (Docking Compartment-1) port and the aft SM (Service Module) port on the ISS. There must always be at least 1 Soyuz available for crew return for a 3-person crew, and 2 Soyuz for a 6-person crew. The current schedule has a 6-person crew at the time of STS-128. As a result, only those configurations with two or more Russian Vehicles docked are considered. A launch delay of 1-5 weeks could result in the presence of the Japanese HTV1 (H-II Transfer Vehicle 1) spacecraft at the zenith CBM of Node2. A launch delay of 3 months could introduce the Russian Mini Research Module (MRM2), a fourth Russian vehicle docking port located on the zenith of the SM. From a mass property standpoint, the STS-128 I-Loads are acceptable with either HTV1 or MRM2.

There are currently 3 primary docking ports to which support vehicles may dock. Table 1 shows the 3 ports, listed in order from fore to aft, with typical occupants for each port.

Table 1: ISS Ports for Visiting Vehicles

Port	Name	Typical Vehicles
FGB-Nadir	Functional Cargo Block	nothing or Soyuz
DC1-Nadir	Docking Compartment-1	nothing, Soyuz, or Progress
SM-Aft	Service Module	nothing, Soyuz, Progress, or ATV

A vehicle swap at the SM aft port causes significant changes in the mated mass properties – sufficient to require distinct mass property I-Loads. The exception is a swap of Soyuz and Progress vehicles, which have very similar mass properties. The other two ports are located farther forward, closer to the composite center-of-mass. A vehicle change at either or both of these ports (FGB nadir and DC1 nadir) may affect performance, but does not usually require distinct mass property I-Load sets.

Since ATV-2 is not scheduled until 2010, Progress and Soyuz spacecraft are the only docked support vehicles expected during STS-128. Consequently, separate mass property I-Loads sets were defined for two different SM aft vehicle possibilities – no vehicle or a Russian vehicle (Progress or Soyuz). Variations at the other two ports were analyzed to ensure adequate performance. To designate the visiting-vehicle variants, a shorthand is used within this document – a 3-letter abbreviation in which the character position represents a docking port, and the initial letter of the vehicle denotes the attached vehicle. The letter “x” designates an empty port. The presence of HTV1 is indicated by an “HTV” after the 3-letter shorthand. Table 2 shows the visiting-vehicle combinations analyzed for flight certification.

Table 2: Port Configuration Nomenclature

Abbrev	FGB-nadir	DC1-nadir	SM-aft	Node2-zenith
RRR	Russian vehicle	Russian vehicle	Russian vehicle	nothing
RRx	Russian vehicle	Russian vehicle	nothing	nothing
RxR	Russian vehicle	nothing	Russian vehicle	nothing
RRR HTV	Russian vehicle	Russian vehicle	Russian vehicle	HTV1
RRx HTV	Russian vehicle	Russian vehicle	nothing	HTV1
RxR HTV	Russian vehicle	nothing	Russian vehicle	HTV1

Most of the analysis details shown in this memorandum are for RRR and RRR HTV since these are the most likely configurations. Summary information is provided for the other configurations. All six have been analyzed and certified for flight; detailed information is available on request. No configuration with MRM2 docked has been certified for STS-128.

Non-RMS Flex Models and Mass Properties All analysis was performed using flex models of the mated stack delivered by Jacobs Technology [13] paired with the appropriate rigid body mass properties from CAMMP (Revision AC) [14]. Table 3 describes the model nomenclature used in this document in terms of the flex models and rigid mass properties used for simulation. Since both the initial and final configurations have the MPLM berthed in the Shuttle payload bay, separate flex models were not needed.

Table 3: Simulation Models Nomenclature

Label	Flex Model	Rigid Body Mass Properties
Initial	Final	CAMMP After Rendezvous (AR)
Intermediate1	Intermediate	CAMMP Intermediate1 (I1)
Final	Final	CAMMP Before Separation (BS)

Jet Modes As with past flights, both VRCS and ALT mode capabilities are provided. Maneuver and attitude hold capabilities are available with VRCS. Attitude hold is available with ALT, but maneuvers are *not* certified with ALT. VRCS control is available for all of the expected STS-128 configurations, including the robotics operations. ALT mode control, on the other hand, has only been certified for attitude hold, and only for the non-robotics portion of the mated flight (see Section 2). The ALT control mode is the same as for the previous mission: 1 jet, with a 7.04 second delay between firings. Since the installation of the S6 truss segment during the STS-119 mission, the control authority with 1-jet ALT mode has deteriorated to the extent that ALT should not be used for attitude maneuvers.

Robotics There are four MPLM SSRMS positions for STS-128, which are used for both MPLM installation and return. Describing function analysis and time domain simulations have been used to certify Orbiter DAP control during these loaded RMS operations (see Section 4). There are also robotics operations during the ATA replacement. At any given time, there will be up to 2 ATAs (one empty and one full) and an EVA astronaut on the SSRMS simultaneously. For the ATA operation, the SSRMS is considered unloaded from an on-orbit flight control perspective.

Reboost Two reboost options are provided for mated flight. The VRCS reboost option is the prime option for STS-128/17A. An ALT PRCS reboost method is provided for the contingency event of the loss of VRCS. The ALT mode reboost is a -Z translation which mimics the VRCS reboost; it was first incorporated into the I-Loads for STS-123 (see Section 5).

Contingency Analysis In addition to the Shuttle control capability designed for nominal operations, limited control capabilities using VRCS were developed for the APU fuel dump scenario. During the APU fuel dump scenario, the desire is to run the APUs at high power (91 hp) to burn off the APU fuel as quickly as possible. An increased rate limit of 0.05°/sec is required during a mated APU fuel dump scenario for STS-128 to avoid violations of the quarter-drift channel criterion; this is the rate limit that was analyzed for this scenario on previous missions.

Deadband Collapse Deadband collapse for direct handover to ISS CMG or USTO control has not been analyzed for STS-128/17A.

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1 Configuration Specific I-Loads for STS-128/17A

I-Loads specific to the mated Orbiter and ISS are required in order for the Orbiter to provide attitude control for the stack. In particular, mass property I-Loads (containing the composite mass properties of the stack) and notch filters (ensuring stability in the presence of flexible body dynamics) must be provided for each Orbiter/ISS mated flight. This section documents the DAP I-Loads for STS-128/17A. Section 1.1 summarizes the DAP I-Load selections for STS-128/17A. Section 1.2 summarizes the I-Load changes needed to support ISS flights in general.

1.1 STS-128/17A Flight Specific I-Load Selections

Table 4 summarizes the STS-128/17A flight specific I-Load selections. OAD 0.01 contains the default occurrences for OI-34 [2]. Of the nine OA categories, one is reserved for non-mated, Orbiter-alone operations, and two are reserved for STS-128/17A mated operations (see Section 2). OA1 is reserved for non-mated OBSS inspection, OA2 is reserved for mated flight while the SM aft port is empty, and OA4 is reserved for mated flight if the SM aft port is occupied by a Russian visiting vehicle (Soyuz or Progress). The RBS occurrence contains the mission specific I-Loads used for Auto Reboost of the mated configuration. The reboost design for this flight uses the same occurrence as on STS-119 through STS-127, which was based on the STS-123 design with the addition of a configuration for Orbiter jettison. The OSE, OVJ, and ZSP categories pertain to the entire flight. The relevant details of each of the I-Load categories are given in subsequent sections.

Table 4: STS-128/17A Mission Specific Occurrences

Category	Occurrence	Description	Status
OAD	0.01	OI-34 Default	D
OA1	4.45	SRMS OBSS	ND
OA2	3.55	2J/A No SM Aft Vehicle	ND
OA3		<i>not used on STS-128</i>	
OA4	3.44	2J/A Progress/Soyuz at SM Aft	ND
OA5		<i>not used on STS-128</i>	
OA6		<i>not used on STS-128</i>	
OA7		<i>not used on STS-128</i>	
OA8		<i>not used on STS-128</i>	
OA9		<i>not used on STS-128</i>	
OSE	2.10	Unique_Filter_Selection_Value=2, 10A Unique Gain Updates	D
OVJ	2.13	STS-104 Jet Selection Changes	D
RBS	1.13	Reboost I-Loads, STS-126	ND
ZSP	5.02	OI-34 Default	D

Status: N=New, D=Default, ND=Not Default

1.2 General I-Load Changes to Support ISS Flights

Table 5 summarizes the values in the OSE, ZSP, and OVJ I-Load categories currently used to support mated Shuttle/ISS operations. In the OSE category, the `Unique_Filter_Selection_Value` is set equal to 2 to utilize the unique filter gains (VRCS) for all payload extended configurations other than OBSS operations. For STS-120 and subsequent ISS assembly flights, the state estimator gains were redesigned in order to provide additional attenuation beyond that of past default state estimator gains [5], thereby improving overall stability with the mated stack. The new gains also help minimize a phenomenon known as “switch-line bouncing”, where flex dynamics can cause the state to bounce back and forth across phase plane switching lines. This “bouncing” can cause jet toggling and has been shown to increase loads and the flex response at the IMU.

The ZSP category values are the OI-34 defaults. The value of the maneuver threshold, KH, is 4; maneuvers will only be triggered if the maneuver angle is four times the deadband. This setting is chosen to minimize maneuver cycling. The S5 scale factor is 0.2 in order to maximize phase plane drift channel height, which is desired for stability reasons. CNTR_MIN and CNTR_MAX retain the values established for STS-123 to prevent shelf-pulsing from tuning into one or more flex modes of the mated stack.

In the OVJ category, the values for `Candidate_Vern_Threshold` and the `Candidate_Alt_Threshold` are the same as the values used in all ISS assembly flights in recent years. They are set to minimize shelf-pulsing as much as possible while still maintaining acceptable performance. Since the `Candidate_Vern_Threshold` is quite a bit different from the nominal Orbiter-alone value, the `Min_Angle_Jet_Select_Value` has been set equal to 2 to remove the dependency of Orbiter-alone VRCS performance on the `Candidate_Vern_Threshold`. The value for `Jet_Mag_Threshold(2)` is 0.27, which has been utilized on past ISS assembly missions, and is needed to ensure proper selection of \pm pitch jet pairs.

Table 5: OSE, ZSP, and OVJ Values

Parameter	MSID	Value	Category
<code>Unique_Filter_Selection_Value</code>	V97U2670C	2	OSE
<code>AF_Inh_Count</code>	V97U3166C	0	OSE
KH	V97U9041C	4.0	ZSP
<code>S5_Scale</code>	V97U9086C	0.2	ZSP
CNTR_MIN	V97U2399C	2	ZSP
CNTR_MAX	V97U2400C	10	ZSP
<code>Min_Angle_Jet_Sel_Value</code>	V97U6301C	2	OVJ
<code>Candidate_Alt_Threshold</code>	V97U6303C	0.0	OVJ
<code>Jet_Mag_Threshold(1)</code>	V97U6304C	0.15	OVJ
<code>Jet_Mag_Threshold(2)</code>	V97U6305C	0.27	OVJ
<code>Jet_Mag_Threshold(3)</code>	V97U6306C	0.30	OVJ
<code>Candidate_Vern_Threshold</code>	V97U6307C	-0.2	OVJ

2 STS-128 Mated Flight, General Strategy, and OAs

2.1 STS-128 Jet Modes for Mated Flight

The standard two jet modes, VRCS and ALT, have been certified for use during mated operations on STS-128. Both VRCS and ALT are certified for attitude hold and reboost. However, only VRCS is certified for attitude maneuvers. The use of ALT mode for maneuvers is not certified due to poor performance (a higher rate of occurrence of maneuver chasing). Attitude holds and maneuvers during robotics operations are certified for VRCS only. For purposes of this memo, the OBSS on either the SRMS or SSRMS may be considered as part of the non-robotics operations *during mated operations*. The required ALT mode and VRCS settings are given in tables throughout this document. Any values of deadbands, maneuver rates, or ALT delays other than those shown in this memo are not allowed without prior analysis by EG and ES to ensure that all ICD [6] and SODB [7] constraints are met. Failure to abide by these settings and constraints may lead to SODB violations, loads exceedances, or other undesirable consequences.

The ALT mode configuration is LowZ with X jets enabled and the forward Y jets (Groups 2 & 3) deselected. For the sake of brevity, this mode will be referred to here as ALT LowZ \pm X NFY to signify the use of the X jets and the deselection of Groups 2 & 3 (NFY: No Forward Y-jets). The deselection of Groups 2 & 3 is required to avoid plume impingement on the outboard solar arrays. The X jets option is required for pitch control during attitude hold. For reboost, however, the X jets option must be disabled. ALT mode is restricted to 1 jet on STS-128/17A. For attitude hold and reboosts, the ALT delay time is 7.04 seconds.

2.2 OA Strategy

The general OA strategy for STS-128 consists of one set of mass properties and one set of notch filters [8] for the entire mated mission for a specific aft vehicle. Due to launch schedule uncertainties, two scenarios were considered concerning the SM aft docking port on the ISS — it may be empty, or it may have a Progress/Soyuz docked. The mass properties of the mated stack for these two scenarios are significantly different from each other; thus two separate groups of I-load mass properties are required to cover the two potential stack configurations. A single OA is needed for STS-128 for all mated operations for a given Russian visiting vehicle scenario. The same notch filter set is in both OAs. This OA strategy is summarized in Table 6.

Table 6: OA Summary

OA	Description	SM Aft Port	Notch Set	VRCS				ALT			
				Hold	Mnvrs	Rbst	RMS	Hold	Mnvrs	Rbst	RMS
OA1	Unmated OBSS Ops	—	None	OK	OK	—	OK	OK	OK	—	OK
OA2	Mated Operations	None	Mated	OK	OK	OK	OK	OK	NO*	OK	—
OA4	Mated Operations	Russian Veh	Mated	OK	OK	OK	OK	OK	NO*	OK	—
				OK: Certified				NO*: Not Certified		— : Not Applicable	
*ALT maneuvers meet stability, SODB, and loads compatibility requirements, but have poor performance due to low controllability											

The non-RMS mated notch filter set from STS-119 is sufficient for all stages of STS-128 mated flight. It has 4 notches near 0.1Hz and two notches near 0.3Hz designed to attenuate the flex oscillation of the ODS and ISS truss modes. This notch filter set is in all mated OA slots.

Category OA1 is provided for Orbiter-alone inspection operations with the OBSS on the Shuttle RMS (SRMS). OA1 is designed to minimize the errors in the DAP's angular increments due to inertia errors in the Orbiter-alone mass property I-Loads. The goal is to keep oscillations of the OBSS/RMS to a minimum during data acquisition.

Categories OA2 and OA4 are for mated operations. These I-Load occurrences are carried over from the STS-127/2JA mission. Therefore, the I-Load titles reflect the original flight for which they were defined. Both of these mated OA categories were designed for a pressurized ODS. These mated OAs have not been certified against the non-linear effects present with an unpressurized ODS (freeplay). Robotics operations have only been certified for VRCS control, and only at the specified way points (see Section 4 for details). See Section 5 for details on the reboost performance and certification. See Section 6 for details on attitude maneuver performance and certification. See Section 7 for details on attitude hold performance and certification.

2.3 Jet and DAP Tables

A summary of the recommended mated DAP settings are shown in Table 7. The DAP tables and jet tables associated with each OA are given in Tables 8 through 16. Table 8 has the I-Loads for the OBSS operations, for reference. Tables 9 through 16 contain the DAPs and jet tables for the mated operations.

Table 7: DAP Setting Summary

DAP SETTINGS	Maneuvers (A12)		Hold (B12)	
	ALT ¹	VRCS	ALT ¹	VRCS
ROT RATE (deg/sec)	≤ 0.05	≤ 0.1	0.01	0.01
ATT DB (deg)	5.0	3.0	1.0	1.0
RATE DB (deg/sec)	0.02	0.02	0.02	0.02
CNTL ACC ²	2,4	2,4	2,4	2,4
¹ ALT mode uses 1 jet, LowZ (Tail), ±X jets enabled, Groups 2 and 3 deselected, 0.08sec ontime, 7.04sec delay				
² CNTL ACC 2 for SM Aft Empty; 4 for Russian vehicle docked at SM Aft				

Table 8: DAP Table and I-Loads for OA1

DAP Table		DAP I-Loads for CNTRL ACC 1				
	A14	Mass Properties				
PRI		Parameter	MSID	Value	Units (info only)	
ROT RATE	≤ 0.2000	X_{cg}	V97U2511C	1097.20	in	
ATT DB	≥ 5.00	Y_{cg}	V97U2512C	0.32	in	
RATE DB	0.20	Z_{cg}	V97U2513C	377.75	in	
ROT PLS	0.10	I_{xx}	V97U2541C	986840	slug-ft ²	
COMP	.000	I_{yy}	V97U2542C	7785100	slug-ft ²	
P OPTION	TAIL	I_{zz}	V97U2543C	8080100	slug-ft ²	
Y OPTION	TAIL	P_{xy}	V97U2571C	-4276	slug-ft ²	
TRAN PLS	0.100	P_{xz}	V97U2572C	299440	slug-ft ²	
ALT		P_{yz}	V97U2573C	1433	slug-ft ²	
RATE DB	0.200	Notch Filter Set				
JET OPT	TAIL	Notch #	MSID	w1 (Hz)	MSID	w2 (Hz)
# JETS	1,2*	1	V97U3101C	0.000000	V97U3102C	0.000000
ON TIME	0.08	2	V97U3103C	0.000000	V97U3104C	0.000000
DELAY	6.0	3	V97U3105C	0.000000	V97U3106C	0.000000
VERN		4	V97U3107C	0.000000	V97U3108C	0.000000
ROT RATE	0.2000	5	V97U3109C	0.000000	V97U3110C	0.000000
ATT DB	3.000	6	V97U3111C	0.000000	V97U3112C	0.000000
RATE DB	0.200	Num_Filters	V97U3161C	0		
ROT PLS	0.010	Notes:				
COMP	.000	* ALT #Jets:				
CNTL ACC	1	=1 for OBSS scan				
PURPOSE	Orbiter Alone SRMS/OBSS	=2 for Orbiter attitude-maneuver				

Table 9: DAP Table and I-loads for OA2

DAP Table		DAP I-Loads for CNTRL ACC 2				
	A12 / B12	Mass Properties				
PRI		Parameter	MSID	Value	Units (info only)	
ROT RATE	≤ 0.05 / 0.01	X_{cg}	V97U2514C	677.32	in	
ATT DB	5 / 1	Y_{cg}	V97U2515C	-29.38	in	
RATE DB	0.20	Z_{cg}	V97U2516C	983.92	in	
ROT PLS	0.040	I_{xx}	V97U2544C	135330000	slug-ft ²	
COMP	.000	I_{yy}	V97U2545C	81103000	slug-ft ²	
P OPTION	TAIL	I_{zz}	V97U2546C	96468000	slug-ft ²	
Y OPTION	TAIL	P_{xy}	V97U2574C	966630	slug-ft ²	
TRAN PLS	0.010	P_{xz}	V97U2575C	-15824000	slug-ft ²	
ALT		P_{yz}	V97U2576C	613200	slug-ft ²	
RATE DB	0.02	Notch Filter Set				
JET OPT	TAIL	Notch #	MSID	w1 (Hz)	MSID	w2 (Hz)
# JETS	1	1	V97U3113C	0.066404	V97U3114C	0.098804
ON TIME	0.08	2	V97U3115C	0.073321	V97U3116C	0.117960
DELAY	7.04	3	V97U3117C	0.086400	V97U3118C	0.135000
VERN		4	V97U3119C	0.102400	V97U3120C	0.160000
ROT RATE	≤ 0.10 / 0.01	5	V97U3121C	0.166320	V97U3122C	0.346320
ATT DB	3 / 1	6	V97U3123C	0.228690	V97U3124C	0.476190
RATE DB	0.02	Num_Filters	V97U3162C	6		
ROT PLS	0.002	Notes:				
COMP	.000	o A12 for maneuvers (VRCS only)				
CNTL ACC	2	o B12 for attitude hold				
PURPOSE	MATED Mnvr/Hold No Aft Veh	o A11 for reboost (non-RMS only) (see Section 5 for DAP settings)				

Table 10: OA2.3.55: VRCS, 2J/A No Aft Vehicle

CMD			Jets			α_x	α_y	α_z	Angle	Projection
R	P	Y				<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg</i>	<i>deg/sec²</i>
-1	-1	-1	L5L	R5D	-	-0.000323	-0.000571	-0.000816	19.45	0.00099
-1	-1	0	F5L	L5D	-	-0.000426	-0.000214	0.000171	26.68	0.00045
-1	-1	1	F5L	R5D	-	-0.000404	-0.000217	0.000542	18.95	0.00067
-1	0	-1	F5L	L5L	L5D	-0.000751	-0.000234	-0.000830	12.14	0.00112
-1	0	0	F5L	L5D	-	-0.000426	-0.000214	0.000171	32.73	0.00043
-1	0	1	F5L	R5D	-	-0.000404	-0.000217	0.000542	19.59	0.00067
-1	1	-1	F5L	L5L	-	-0.000730	0.000314	-0.000644	17.67	0.00097
-1	1	0	F5L	-	-	-0.000405	0.000334	0.000357	34.58	0.00052
-1	1	1	F5L	-	-	-0.000405	0.000334	0.000357	4.65	0.00063
0	-1	-1	L5L	R5D	L5D	-0.000344	-0.001119	-0.001002	13.26	0.00150
0	-1	0	R5D	L5D	-	-0.000019	-0.001099	-0.000001	1.00	0.00110
0	-1	1	R5R	R5D	L5D	0.000305	-0.001142	0.001000	11.96	0.00152
0	0	-1	F5R	L5L	L5D	0.000018	-0.000238	-0.001539	8.80	0.00154
0	0	1	F5L	R5R	R5D	-0.000080	-0.000260	0.001543	9.99	0.00154
0	1	-1	F5R	F5L	L5L	-0.000367	0.000644	-0.000996	20.90	0.00116
0	1	0	F5R	F5L	-	-0.000042	0.000664	0.000005	3.63	0.00066
0	1	1	F5R	F5L	R5R	0.000282	0.000621	0.001007	18.81	0.00115
1	-1	-1	F5R	R5D	-	0.000365	-0.000221	-0.000167	18.41	0.00044
1	-1	0	F5R	R5D	-	0.000365	-0.000221	-0.000167	25.30	0.00041
1	-1	1	R5R	L5D	-	0.000303	-0.000591	0.000816	20.20	0.00099
1	0	-1	F5R	L5D	-	0.000343	-0.000218	-0.000538	22.48	0.00062
1	0	0	F5R	R5D	-	0.000365	-0.000221	-0.000167	37.18	0.00036
1	0	1	F5R	R5R	R5D	0.000689	-0.000264	0.000834	14.72	0.00108
1	1	-1	F5R	-	-	0.000364	0.000330	-0.000352	2.27	0.00060
1	1	0	F5R	-	-	0.000364	0.000330	-0.000352	35.72	0.00049
1	1	1	F5R	R5R	-	0.000687	0.000287	0.000650	18.42	0.00094
			Averages			MCA				
			RSS:			0.00091	Roll		0.00071	
			Angle:			18.06	Pitch		0.00088	
			Proj:			0.00087	Yaw		0.00100	

Table 11: OA2.3.55: 1-jet, ALT-LowZ±X NFY, 2J/A No Aft Vehicle

CMD			Jets	α_x	α_y	α_z	Angle	Projection
R	P	Y		<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg</i>	<i>deg/sec²</i>
-1	-1	-1	L4D - -	-0.002569	-0.023683	-0.011698	34.35	0.02191
-1	-1	0	F1F - -	0.000227	-0.033674	0.001449	45.44	0.02365
-1	-1	1	R4D - -	0.001703	-0.023910	0.011573	42.89	0.01950
-1	0	-1	L3L - -	-0.011947	-0.000238	-0.035806	26.55	0.03377
-1	0	0	F3D - -	-0.014194	0.011542	0.012180	49.77	0.01419
-1	0	1	F3D - -	-0.014194	0.011542	0.012180	31.95	0.01865
-1	1	-1	L3L - -	-0.011947	-0.000238	-0.035806	43.39	0.02743
-1	1	0	F3D - -	-0.014194	0.011542	0.012180	34.11	0.01820
-1	1	1	F3D - -	-0.014194	0.011542	0.012180	5.11	0.02189
0	-1	-1	L4D - -	-0.002569	-0.023683	-0.011698	19.49	0.02502
0	-1	0	F1F - -	0.000227	-0.033674	0.001449	2.49	0.03367
0	-1	1	R4D - -	0.001703	-0.023910	0.011573	19.51	0.02509
0	0	-1	L3L - -	-0.011947	-0.000238	-0.035806	18.46	0.03581
0	0	1	R3R - -	0.011998	-0.001043	0.035244	18.87	0.03524
0	1	-1	R1A - -	0.001527	0.033618	-0.007521	32.48	0.02909
0	1	0	L1A - -	-0.001348	0.033561	0.004573	8.09	0.03356
0	1	1	L1A - -	-0.001348	0.033561	0.004573	37.30	0.02696
1	-1	-1	L4D - -	-0.002569	-0.023683	-0.011698	44.45	0.01894
1	-1	0	F1F - -	0.000227	-0.033674	0.001449	44.67	0.02397
1	-1	1	R4D - -	0.001703	-0.023910	0.011573	36.24	0.02147
1	0	-1	F4D - -	0.012684	0.011405	-0.012006	33.18	0.01746
1	0	0	F4D - -	0.012684	0.011405	-0.012006	52.55	0.01268
1	0	1	R3R - -	0.011998	-0.001043	0.035244	26.25	0.03340
1	1	-1	F4D - -	0.012684	0.011405	-0.012006	2.49	0.02084
1	1	0	F4D - -	0.012684	0.011405	-0.012006	35.26	0.01703
1	1	1	R3R - -	0.011998	-0.001043	0.035244	44.26	0.02667
			Averages	MCA				
			RSS:	0.02920		Roll	0.02115	
			Angle:	30.37		Pitch	0.03365	
			Proj:	0.02447		Yaw	0.03553	

Table 12: OA2.3.55: 1-jet, ALT-LowZ NFY (Reboost), 2J/A No Aft Vehicle

CMD			Jets	α_x	α_y	α_z	Angle	Projection
R	P	Y		<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg</i>	<i>deg/sec²</i>
-1	-1	-1	L4D - -	-0.002569	-0.023683	-0.011698	34.35	0.02191
-1	-1	0	L4D - -	-0.002569	-0.023683	-0.011698	45.62	0.01856
-1	-1	1	R4D - -	0.001703	-0.023910	0.011573	42.89	0.01950
-1	0	-1	L3L - -	-0.011947	-0.000238	-0.035806	26.55	0.03377
-1	0	0	F3D - -	-0.014194	0.011542	0.012180	49.77	0.01419
-1	0	1	F3D - -	-0.014194	0.011542	0.012180	31.95	0.01865
-1	1	-1	L3L - -	-0.011947	-0.000238	-0.035806	43.39	0.02743
-1	1	0	F3D - -	-0.014194	0.011542	0.012180	34.11	0.01820
-1	1	1	F3D - -	-0.014194	0.011542	0.012180	5.11	0.02189
0	-1	-1	L4D - -	-0.002569	-0.023683	-0.011698	19.49	0.02502
0	-1	0	R4D - -	0.001703	-0.023910	0.011573	26.07	0.02391
0	-1	1	R4D - -	0.001703	-0.023910	0.011573	19.51	0.02509
0	0	-1	L3L - -	-0.011947	-0.000238	-0.035806	18.46	0.03581
0	0	1	R3R - -	0.011998	-0.001043	0.035244	18.87	0.03524
0	1	-1	F4D - -	0.012684	0.011405	-0.012006	37.48	0.01655
0	1	0	F4D - -	0.012684	0.011405	-0.012006	56.86	0.01141
0	1	1	F3D - -	-0.014194	0.011542	0.012180	40.25	0.01677
1	-1	-1	L4D - -	-0.002569	-0.023683	-0.011698	44.45	0.01894
1	-1	0	R4D - -	0.001703	-0.023910	0.011573	47.12	0.01811
1	-1	1	R4D - -	0.001703	-0.023910	0.011573	36.24	0.02147
1	0	-1	F4D - -	0.012684	0.011405	-0.012006	33.18	0.01746
1	0	0	F4D - -	0.012684	0.011405	-0.012006	52.55	0.01268
1	0	1	R3R - -	0.011998	-0.001043	0.035244	26.25	0.03340
1	1	-1	F4D - -	0.012684	0.011405	-0.012006	2.49	0.02084
1	1	0	F4D - -	0.012684	0.011405	-0.012006	35.26	0.01703
1	1	1	R3R - -	0.011998	-0.001043	0.035244	44.26	0.02667
			Averages	MCA				
			RSS:	0.02689		Roll	0.02115	
			Angle:	33.56		Pitch	0.01773	
			Proj:	0.02194		Yaw	0.03553	

Table 13: DAP Table and I-loads for OA4

DAP Table		DAP I-Loads for CNTRL ACC 4				
	A12 / B12	Mass Properties				
PRI		Parameter	MSID	Value	Units (info only)	
ROT RATE	≤ 0.05 / 0.01	X_{cg}	V97U2520C	675.07	in	
ATT DB	5 / 1	Y_{cg}	V97U2521C	-28.86	in	
RATE DB	0.20	Z_{cg}	V97U2522C	1011.70	in	
ROT PLS	0.040	I_{xx}	V97U2550C	144180000	slug-ft ²	
COMP	.000	I_{yy}	V97U2551C	90004000	slug-ft ²	
P OPTION	TAIL	I_{zz}	V97U2552C	96533000	slug-ft ²	
Y OPTION	TAIL	P_{xy}	V97U2580C	953150	slug-ft ²	
TRAN PLS	0.010	P_{xz}	V97U2581C	-16540000	slug-ft ²	
ALT		P_{yz}	V97U2582C	779960	slug-ft ²	
RATE DB	0.02	Notch Filter Set				
JET OPT	TAIL	Notch #	MSID	w1 (Hz)	MSID	w2 (Hz)
# JETS	1	1	V97U3137C	0.066404	V97U3138C	0.098804
ON TIME	0.08	2	V97U3139C	0.073321	V97U3140C	0.117960
DELAY	7.04	3	V97U3141C	0.086400	V97U3142C	0.135000
VERN		4	V97U3143C	0.102400	V97U3144C	0.160000
ROT RATE	≤ 0.10 / 0.01	5	V97U3145C	0.166320	V97U3146C	0.346320
ATT DB	3 / 1	6	V97U3147C	0.228690	V97U3148C	0.476190
RATE DB	0.02	Num_Filters	V97U3164C	6		
ROT PLS	0.002	Notes:				
COMP	.000	o A12 for maneuvers (VRCS only)				
CNTL ACC	4	o B12 for attitude hold				
PURPOSE	MATED Mnvr/Hold Progress Aft	o A11 for reboost (non-RMS only) (see Section 5 for DAP settings)				

Table 14: OA4.3.44: VRCS, 2J/A Progress/Soyuz Aft

CMD			Jets			α_x	α_y	α_z	Angle	Projection
R	P	Y				<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg</i>	<i>deg/sec²</i>
-1	-1	-1	L5L	R5D	-	-0.000318	-0.000509	-0.000816	20.55	0.00095
-1	-1	0	F5L	R5D	L5D	-0.000416	-0.000685	0.000356	27.42	0.00078
-1	-1	1	F5L	R5D	L5D	-0.000416	-0.000685	0.000356	16.42	0.00084
-1	0	-1	F5L	L5L	L5D	-0.000742	-0.000209	-0.000830	11.08	0.00111
-1	0	0	F5L	L5D	-	-0.000420	-0.000192	0.000171	31.48	0.00042
-1	0	1	F5L	R5D	-	-0.000393	-0.000196	0.000541	18.59	0.00066
-1	1	-1	F5L	L5L	-	-0.000719	0.000281	-0.000645	19.27	0.00095
-1	1	0	F5L	-	-	-0.000397	0.000297	0.000356	36.49	0.00049
-1	1	1	F5L	-	-	-0.000397	0.000297	0.000356	6.71	0.00061
0	-1	-1	L5L	R5D	L5D	-0.000340	-0.000998	-0.001001	13.54	0.00141
0	-1	0	R5D	L5D	-	-0.000018	-0.000982	-0.000000	1.08	0.00098
0	-1	1	R5R	R5D	L5D	0.000303	-0.001022	0.001002	11.95	0.00143
0	0	-1	F5R	L5L	L5D	0.000015	-0.000210	-0.001539	7.81	0.00154
0	0	1	F5L	R5R	R5D	-0.000072	-0.000236	0.001543	9.09	0.00154
0	1	-1	F5R	F5L	L5L	-0.000360	0.000576	-0.000997	22.79	0.00111
0	1	0	F5R	F5L	-	-0.000038	0.000592	0.000004	3.70	0.00059
0	1	1	F5R	F5L	R5R	0.000283	0.000552	0.001006	21.25	0.00110
1	-1	-1	F5R	R5D	L5D	0.000341	-0.000687	-0.000352	19.24	0.00080
1	-1	0	F5R	R5D	-	0.000363	-0.000198	-0.000167	27.20	0.00040
1	-1	1	R5R	L5D	-	0.000298	-0.000530	0.000816	21.14	0.00095
1	0	-1	F5R	L5D	-	0.000336	-0.000194	-0.000537	21.28	0.00062
1	0	0	F5R	R5D	-	0.000363	-0.000198	-0.000167	35.44	0.00036
1	0	1	F5R	R5R	R5D	0.000685	-0.000238	0.000835	13.64	0.00107
1	1	-1	F5R	-	-	0.000359	0.000295	-0.000352	4.89	0.00058
1	1	0	F5R	-	-	0.000359	0.000295	-0.000352	37.50	0.00046
1	1	1	F5R	R5R	-	0.000680	0.000255	0.000650	20.15	0.00092
			Averages			MCA				
			RSS:			0.00092	Roll		0.00070	
			Angle:			18.45	Pitch		0.00079	
			Proj:			0.00087	Yaw		0.00100	

Table 15: OA4.3.44: 1-jet, ALT-LowZ±X NFY, 2J/A Progress/Soyuz Aft

CMD			Jets	α_x	α_y	α_z	Angle	Projection
R	P	Y		<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg</i>	<i>deg/sec²</i>
-1	-1	-1	L4D - -	-0.002646	-0.021101	-0.011667	32.55	0.02045
-1	-1	0	F1F - -	0.000184	-0.031618	0.001473	45.40	0.02223
-1	-1	1	R4D - -	0.001810	-0.021349	0.011593	42.45	0.01797
-1	0	-1	L3L - -	-0.011836	-0.000150	-0.035809	26.71	0.03369
-1	0	0	F3D - -	-0.013923	0.010261	0.012152	48.80	0.01392
-1	0	1	F3D - -	-0.013923	0.010261	0.012152	29.28	0.01844
-1	1	-1	L3L - -	-0.011836	-0.000150	-0.035809	43.36	0.02742
-1	1	0	F3D - -	-0.013923	0.010261	0.012152	36.00	0.01710
-1	1	1	F3D - -	-0.013923	0.010261	0.012152	7.04	0.02098
0	-1	-1	L4D - -	-0.002646	-0.021101	-0.011667	17.21	0.02317
0	-1	0	F1F - -	0.000184	-0.031618	0.001473	2.69	0.03162
0	-1	1	R4D - -	0.001810	-0.021349	0.011593	17.02	0.02329
0	0	-1	L3L - -	-0.011836	-0.000150	-0.035809	18.29	0.03581
0	0	1	R3R - -	0.011886	-0.001002	0.035248	18.70	0.03525
0	1	-1	R1A - -	0.001486	0.031589	-0.007540	31.67	0.02767
0	1	0	L1A - -	-0.001271	0.031513	0.004548	8.52	0.03151
0	1	1	L1A - -	-0.001271	0.031513	0.004548	36.85	0.02550
1	-1	-1	L4D - -	-0.002646	-0.021101	-0.011667	44.20	0.01739
1	-1	0	F1F - -	0.000184	-0.031618	0.001473	44.73	0.02249
1	-1	1	R4D - -	0.001810	-0.021349	0.011593	34.55	0.02006
1	0	-1	F4D - -	0.012549	0.010190	-0.012012	30.42	0.01737
1	0	0	F4D - -	0.012549	0.010190	-0.012012	51.46	0.01255
1	0	1	R3R - -	0.011886	-0.001002	0.035248	26.41	0.03333
1	1	-1	F4D - -	0.012549	0.010190	-0.012012	4.98	0.02006
1	1	0	F4D - -	0.012549	0.010190	-0.012012	37.02	0.01608
1	1	1	R3R - -	0.011886	-0.001002	0.035248	44.30	0.02663
			Averages	MCA				
			RSS:	0.02796		Roll	0.02074	
			Angle:	30.02		Pitch	0.03160	
			Proj:	0.02354		Yaw	0.03553	

Table 16: OA4.3.44: 1-jet, ALT-LowZ NFY (Reboost), 2J/A Progress/Soyuz Aft

CMD			Jets	α_x	α_y	α_z	Angle	Projection
R	P	Y		<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg/sec²</i>	<i>deg</i>	<i>deg/sec²</i>
-1	-1	-1	L4D - -	-0.002646	-0.021101	-0.011667	32.55	0.02045
-1	-1	0	L4D - -	-0.002646	-0.021101	-0.011667	46.19	0.01679
-1	-1	1	R4D - -	0.001810	-0.021349	0.011593	42.45	0.01797
-1	0	-1	L3L - -	-0.011836	-0.000150	-0.035809	26.71	0.03369
-1	0	0	F3D - -	-0.013923	0.010261	0.012152	48.80	0.01392
-1	0	1	F3D - -	-0.013923	0.010261	0.012152	29.28	0.01844
-1	1	-1	L3L - -	-0.011836	-0.000150	-0.035809	43.36	0.02742
-1	1	0	F3D - -	-0.013923	0.010261	0.012152	36.00	0.01710
-1	1	1	F3D - -	-0.013923	0.010261	0.012152	7.04	0.02098
0	-1	-1	L4D - -	-0.002646	-0.021101	-0.011667	17.21	0.02317
0	-1	0	R4D - -	0.001810	-0.021349	0.011593	28.79	0.02135
0	-1	1	R4D - -	0.001810	-0.021349	0.011593	17.02	0.02329
0	0	-1	L3L - -	-0.011836	-0.000150	-0.035809	18.29	0.03581
0	0	1	R3R - -	0.011886	-0.001002	0.035248	18.70	0.03525
0	1	-1	F4D - -	0.012549	0.010190	-0.012012	38.79	0.01570
0	1	0	F4D - -	0.012549	0.010190	-0.012012	59.61	0.01019
0	1	1	F3D - -	-0.013923	0.010261	0.012152	41.43	0.01585
1	-1	-1	L4D - -	-0.002646	-0.021101	-0.011667	44.20	0.01739
1	-1	0	R4D - -	0.001810	-0.021349	0.011593	47.76	0.01638
1	-1	1	R4D - -	0.001810	-0.021349	0.011593	34.55	0.02006
1	0	-1	F4D - -	0.012549	0.010190	-0.012012	30.42	0.01737
1	0	0	F4D - -	0.012549	0.010190	-0.012012	51.46	0.01255
1	0	1	R3R - -	0.011886	-0.001002	0.035248	26.41	0.03333
1	1	-1	F4D - -	0.012549	0.010190	-0.012012	4.98	0.02006
1	1	0	F4D - -	0.012549	0.010190	-0.012012	37.02	0.01608
1	1	1	R3R - -	0.011886	-0.001002	0.035248	44.30	0.02663
			Averages	MCA				
			RSS:	0.02577		Roll	0.02074	
			Angle:	33.59		Pitch	0.01580	
			Proj:	0.02105		Yaw	0.03553	

2.4 General Recommendations

2.4.1 Mission-Specific Recommendations for STS-128

- **CMG Gimbal Positioning During Orbiter Control**
Station CMGs should not be repositioned during reboost or during attitude maneuvers. The end of a maneuver should be understood to be when the attitude rates are damped, not when the magnitude of the attitude error is within the attitude deadband.
- **CMGs in Inertial-Drift Mode During Orbiter Control**
The CMGs should be in Inertial-Drift mode during long-term Orbiter control. Otherwise, the CMGs will impart a disturbance to Orbiter control which will invalidate predictions regarding Orbiter performance and control authority.
- **Attitude Maneuver and Attitude Hold DAP Settings**
The maneuver DAP settings should be selected when performing maneuvers. The hold DAP settings will provide improved performance for attitude hold. The only time the VRCS attitude hold DAP settings are required is at undocking, where they are necessary to satisfy the undocking attitude and rate error requirements.
- **PRCS Reboost Performance**
No mated reboost is scheduled for the STS-128 mission. If a reboost is required after a VRCS failure (for a collision avoidance reboost, for example), the 1-jet PRCS reboost capability is available. However, if ISS thrusters are available, we recommend the use of an ISS attitude control system to maneuver to the reboost attitude (if a maneuver is required).

2.4.2 Other Recommendations

- **Deselection of IMU**
Recommend deselection of an IMU during mated attitude control to avoid IMU ID switching. IMU ID switching can produce undesirable transients that result in increased propellant usage, as was observed during mated Mir operations.
- **-7.5 Elevon Park**
Recommend parking the elevons at -7.5 to minimize VRCS plume impingement. This is especially important for maximizing reboost efficiency.
- **Downlist the Undesired Control Accels**
As was requested for previous ISS assembly flights, the undesired accels should be downlisted to aid assessment of any control problems that might occur during STS-128.
- **Pressurized ODS Required for Mated Flight Control**
ODS pressure must be greater than 3.45 psi to avoid nonlinear dynamics at the ODS.
- **Loss of Any VRCS Thruster Prohibits Use of Mated VRCS Control**
Loss of any VRCS thruster will result in loss of mated vehicle VRCS control capability. The back-up control mode must be selected as soon as possible.

- **Select FREE Prior to Changing Control Accel Values**

When moding between control accels (OAs) that have different notch filters, FREE should be selected prior to entering the new control accel value and maintained for 30 seconds after the execution of the new value. This procedure allows any rate and acceleration estimate transients resulting from the notch update to settle prior to engaging control. *All of the mated OAs for STS-128 have the same notches.*

- **When Moding from FREE to Shuttle Control, Mode to LVLH (INRTL) prior to AUTO**

When moding from FREE to shuttle control, LVLH (INRTL) should be selected prior to moding to AUTO to sufficiently damp rates. LVLH should be selected if the subsequent maneuver is to an LVLH attitude; INTRL should be selected if the maneuver is to an inertially referenced attitude. The manual LVLH(INRTL) mode should be maintained long enough for DAP rates to stabilize to the desired rate.

- **Mode through FREE when transitioning from LVLH to AUTO**

Anytime AUTO control is required following a period of LVLH hold, the DAP should be moded to FREE for at least 2 seconds before selecting AUTO. This procedure is required to prevent the DAP from using a stale time reference (the time LVLH was entered) in the calculation of the initial attitude bias at auto maneuver start.

- **After GPC Reset, Stay in FREE Until Undesired Accels Values are Less than 1/2 the Control Acceleration before Going to Shuttle Control**

During a GPC set contraction or expansion, the GPCs are reset and the DAP is re-initialized. This produces a temporary transient in the Undesired Accels until the state estimator converges. To avoid the impact from the transient, the Undesired Accels in each of the three axes should be monitored and the DAP should stay in FREE until the Undesired Accel in each axis goes below 1/2 the respective effective MCA for that axis. See Table 17 for these values and Section 3 for a more in-depth explanation.

- **Proper Control Authority Must be Maintained During Propulsive Venting**

Propulsive venting results in a disturbance upon the vehicle that must be countered by the jets. Under most shuttle alone conditions, the jets have more than sufficient control authority to overcome any vent disturbance. However, while mated to the ISS, constraints and limitations on Orbiter jets may result in the DAP being unable to fully oppose a venting disturbance. For full details see Section 3.

3 Control Authority and Undesired Accels

For the Orbiter to provide effective control of the mated stack, the control acceleration must always exceed the disturbance acceleration. If the disturbance acceleration is greater than the control acceleration, then the autopilot will not be able to maintain attitude control within the prescribed rate limits and deadbands. Under most circumstances the acceleration available from the jets is quite large compared to any likely disturbance acceleration. However, with the ISS as a payload there are scenarios for which the disturbance acceleration can approach or exceed the available control authority. If this occurs during a flight, then there is a risk of temporary loss of attitude control. Such a scenario can be avoided by noting the control authority the DAP has versus the expected disturbance acceleration.

The DAP estimates the available control authority from the jets via the on-board I-Load calculation. This estimate is referred to as the MCA (Magnitude of Control Acceleration). These values represent a best estimate of the single-axis acceleration available to the DAP and are used to determine when and how long to fire jets. Values of the MCAs for STS-128/17A are given in Table 17. Note that the values for ALT were adjusted to reflect the reduced control authority resulting from the ALT delay and on-time restrictions.

Table 17: MCA for STS-128 Mated Jet Modes

CNTRL ACCEL	Mated Orbiter/ISS Jet Modes	MCA (deg/sec ²)			$\frac{1}{2}$ (MCA) (deg/sec ²)		
		Roll	Pitch	Yaw	Roll	Pitch	Yaw
OA2	VRCS	7.10E-04	8.80E-04	1.00E-03	3.55E-04	4.40E-04	5.00E-04
	1-Jet ALT, 7.04 sec	2.38E-04	3.78E-04	3.99E-04	1.19E-04	1.89E-04	2.00E-04
OA4	VRCS	7.00E-04	7.90E-04	1.00E-03	3.50E-04	3.95E-04	5.00E-04
	1-Jet ALT, 7.04 sec	2.33E-04	3.55E-04	3.99E-04	1.17E-04	1.78E-04	2.00E-04

Disturbances on the vehicle are measured by the DAP via the state estimator. Taking the IMU increments and running the measurements through a Kalman filter results in estimates of the body rates and any disturbances due to unmodeled accelerations. These disturbances are referred to as the Undesired Accels. The DAP takes these into account in order to control the vehicle by computing the effective control authority it has available. The effective control authority available is computed by the DAP as the difference between the acceleration available from the jets (the MCAs) less the disturbance acceleration (Undesired Accels). As the effective control authority shrinks, control becomes increasingly worse. Should the effective control authority become zero or negative, then control is physically impossible.

There are two primary scenarios of note on STS-128/17A where the effective control authority can approach zero or even go negative. The first scenario is when the GPCs are reset. The reset causes the re-initialization of the DAP and a subsequent transient in the Undesired Accel values due to the re-initialization of the state estimator. The second scenario concerns venting. The resulting disturbances from some vents, in particular the propulsive vents associated with the Orbiter airlock and the APU, can exceed the control authority of some of the control modes for ISS assembly. In these scenarios there is a risk of loss of attitude control if an inappropriate control mode is selected

during venting. Such a loss of control can result in serious consequences depending upon the causes and duration. Other scenarios probably exist where the effective control authority can approach zero or even go negative, so it should be kept in mind that the GPC and venting scenarios do not constitute a complete list.

3.1 GPC Set Contraction

During GPC set contraction, the GPCs are reset and the DAP is re-initialized. This procedure re-initializes the state estimator setting the body rates and accelerations to zero. This reset results in a temporary transient in the Undesired Accels that lasts for approximately 300 seconds until the state estimator can converge on the correct rates and disturbance accelerations. During part of this period, the Undesired Accels will almost assuredly exceed the MCA values. This problem can be managed by staying in free drift until the Undesired Accel values in the downlist are less than half the available control acceleration (see Table 17). Failure to observe this procedure may cause temporary loss of control, extra jet firings, and wasted propellant.

Figure 1 shows an example of the effect GPC set contraction can have on the Undesired Accels. During STS-126, a GPC set contraction was performed in the middle of the post-docking maneuver. The actual rate did not change during the reset, but the filter required time for the rate estimate to converge (top plot). The spike in the roll Undesired Accel is shown in the lower plot. The state estimator required about 3 minutes (in this example) for the undesired acceleration to reach the half-MCA mark. This is not a problem if adequate time is allowed for the rate estimate to converge, as on STS-126.

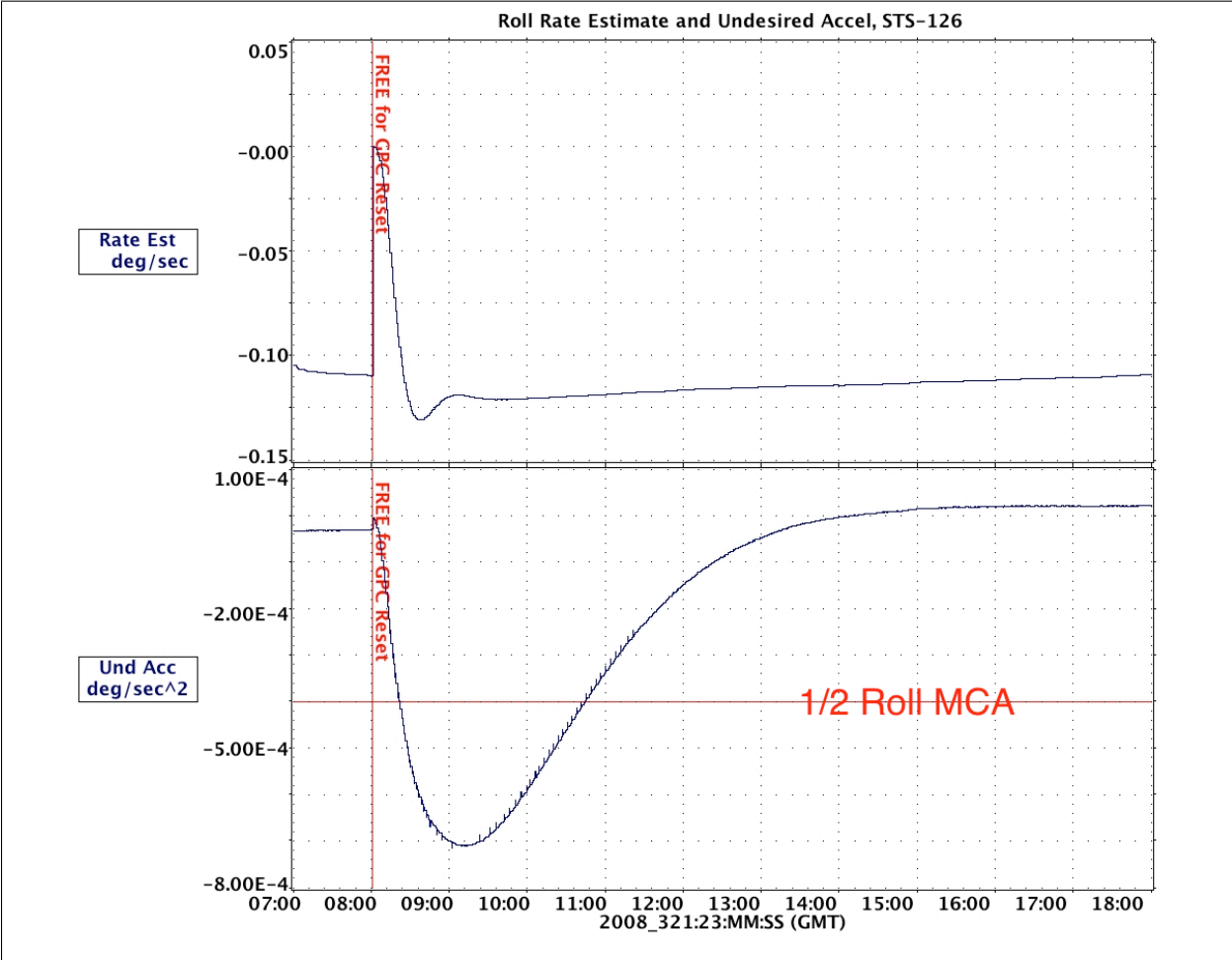


Figure 1: Example of Undesired Accel Transients During GPC Set Contraction

3.2 Propulsive Venting

There are several sources of propulsive venting on the mated stack. The usual water dump and FES vent disturbances are small and not an issue for shuttle control. However, there are two main sources of propulsive venting that are of particular concern, and known scenarios exist where these vents may be activated. The first case involves the venting of the ODS and the second case involves APU venting.

In any venting scenario, the available control acceleration must exceed the disturbance acceleration due to venting. Since the DAP will respond to multi-axis commands, and thus the effective control acceleration may be less than the single-axis control acceleration shown in Table 17, the rule of thumb to apply is that the control acceleration should exceed the venting disturbance acceleration by a factor of 2 or more.

3.2.1 Airlock Venting

Nominal venting through the ODS/external airlock depressurization vents results in a near non-propulsive venting of the airlock and is not a concern. However, certain airlock vents on the Orbiter can put a considerable disturbance on the mated stack. Past analyses have shown that under certain scenarios these vents can exceed the DAP's control authority for some jet modes. Should any of these venting scenarios occur, care must be taken to ensure the DAP has adequate control authority to oppose the vent force.

The vents of concern are the three hatch equalization valves (HEV): the External Airlock Aft HEV, the ODS Upper HEV, and the Spacehab Tunnel Adaptor HEV. Each of these valves may be operated in one of two modes, normal and emergency. Emergency mode corresponds to a larger effective valve radius, higher flow rate, and therefore greater propulsive force than normal mode.

Venting through the ODS Upper HEV and the Spacehab Tunnel Adaptor HEV are well under the half MCA criteria in all three axes for all jet control modes. Thus there is no concern in using either ALT or VRCS to control during venting of the ODS Upper HEV or the Spacehab Tunnel Adaptor.

However, emergency mode venting from the External Airlock Aft HEV at an initial airlock pressure of 14.7 psi produces disturbance accelerations in pitch that are significant compared to the MCAs. Worst-case disturbance accelerations are greater than 1/2 the MCA for both ALT and VRCS mode. VRCS mode has sufficient control authority in the normal vent mode, while ALT mode does not. Therefore, propulsive venting from the External Airlock Aft HEV during mated Orbiter/ISS operations is only permitted with VRCS control and in normal vent mode. Emergency mode may be permissible if the airlock is first depressurized to an acceptable level using the normal vent mode.

3.2.2 APU Fuel Dump

In the event that an APU fuel leak is discovered, the procedure is to burn off APU fuel as quickly as possible to prevent contamination of the aft section of the Orbiter. To accomplish this goal the APU is run at high horsepower and the WSB (Water Spray Boiler) is expected to come on. Complete fuel burn-off is expected to take approximately 55 minutes. A limited capability for Orbiter control has been developed for this contingency.

Tables 18 and 19 give the location of the relevant vents. Figure 2 shows the vent force as a function of time. The APU vent force is not a constant over time, but varies from a peak near 30 lbs to a low of zero. The horsepower setting determines the cycling of the vent and ultimately the average vent force. The average thrust is close to 14 lbs. Added to this is the WSB, which contributes a thrust of approximately 3 lbs, for a total thrust of approximately 17 lbs.

The timeline for the APU fuel dump, shown in Table 20, includes the FCS Checkout as well as the other changes to the procedure [9] made for STS-124 and subsequent flights. The vent force is about 65% of the available VRCS control force. The resulting disturbance acceleration is approximately $0.0006^\circ/\text{sec}^2$. Comparison to Table 17 shows that this disturbance exceeds the MCA for ALT mode, and thus ALT mode control during APU fuel dumps is not an option. The disturbance also exceeds the 1/2 MCA limit for VRCS, and thus at best the DAP will only marginally be able to handle the APU fuel dump scenario.

Table 18: APU Vent locations

	X loc fab inches	Y loc fab inches	Z loc fab inches
APU 1:	1327.9	-15.9	502.5
APU 2:	1318.7	-15.7	501.3
APU 3:	1327.9	15.9	502.5

Table 19: WSB Vent locations

	X loc fab inches	Y loc fab inches	Z loc fab inches
WSB 1:	1375.7	16.3	508.1
WSB 2:	1395.7	16.3	510.5
WSB 3:	1355.7	16.4	505.8

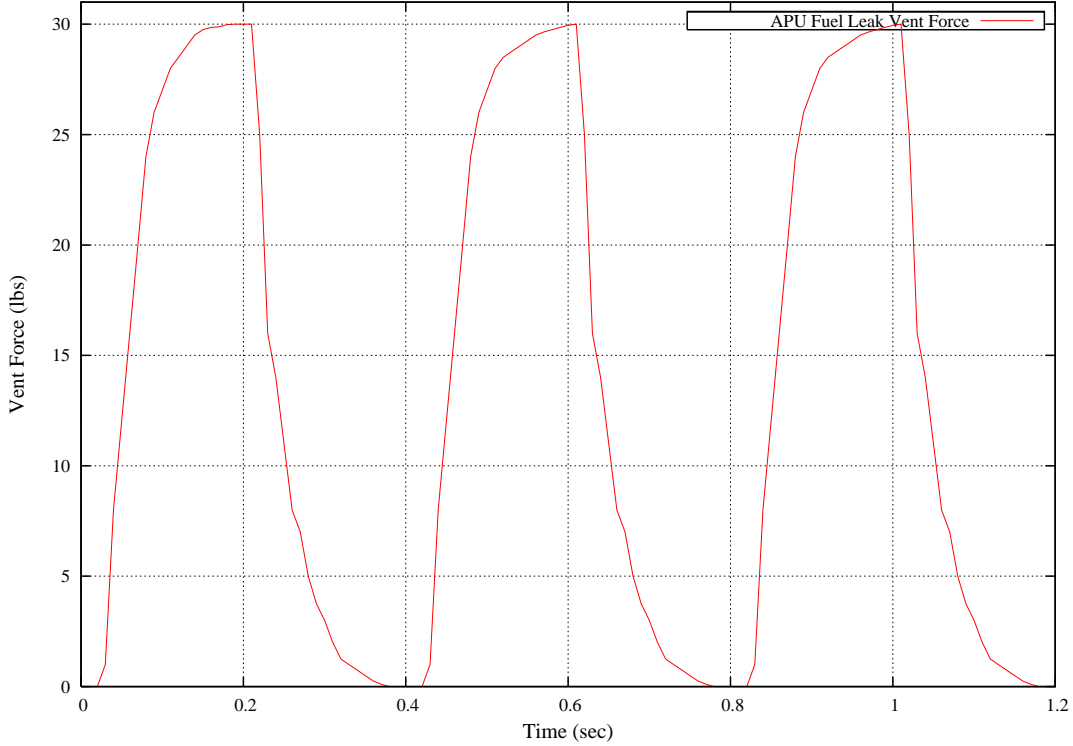


Figure 2: APU Vent Force Time History

Table 20: APU Fuel Dump Timeline

Event	Time (sec)	Average Thrust (lbs)	Approximate Equivalent Horsepower
APU Start	0	0	0
Low Press	15	2.4	-
Norm Press	30	2.9	28
Aerosurface Drive Initiate	60	14.3	91
Aerosurface Drive Stop	90	2.9	28
Secondary Actuator Check	105	2.9	28
End Secondary Actuator Check	270	2.9	28
Aerosurface Drive Initiate	300	14.3	91
WSB Spraying Begins	450	17.3	91
Aerosurface Drive Stop	3240	5.9	-
APU Fuel Tank Depletion	3300	0	0

For each TEA in the April 20, 2009 Basic ATL, 100 Monte Carlo cases were run using the VRCS maneuver DAP with a modified rate limit of 0.05 deg/sec and using the APU thrust profile for the APU fuel dump scenario of Figure 2. Mass property dispersions of $\pm 1\%$ in inertia and ± 6 inches in center of mass, initial rate error dispersions of ± 0.01 deg/sec, and modal uncertainties of ± 4 dB in amplitude and $\pm 20\%$ in frequency were applied to each of the cases. The dominating disturbance

of the dump, the vent force, has roughly the same moment arm as the VRCS jets fired by the DAP to counteract the disturbance. As a result, the expected propellant cost can be estimated by multiplying the ratio of the vent force to the VRCS jet force by the vernier jet flow rate and the length of the dump in seconds.

$$PropCost = APUVentForce/VernierJetForce \times VernierFuelFlowRate \times \# Jets \times Time \quad (1)$$

The two down-firing vernier jets have a net force (i.e. less self-impingement) of approximately 13 lbs each, for a total of 26 lbs. Vernier flow rates are 0.091 lbs/sec/jet, and there are two jets. Thus an average APU vent force of 17 lbs for a dump of approximately 3300 seconds yields a ballpark estimate of 393 lbs. Table 21 summarizes the observed propellant usages for the APU fuel dump scenario. The Orbiter body attitude relative to LVLH expressed by a PYR Euler angle sequence is given in RPY order. Table 22 summarizes the jet firing statistics for the APU fuel dump. All of the SODB jet firing constraints are met.

Table 21: STS-128/17A APU Fuel Dump Propellant Usages, RRR

ATL Attitude	Total lbs/hr	1 σ lbs/hr	Aft lbs/hr	1 σ lbs/hr	Fwd lbs/hr	1 σ lbs/hr
28: 192.06 72.96 358.39	379.31	10.92	357.67	4.98	21.64	6.87
29: 168.10 73.82 5.64	379.92	10.04	357.22	5.00	22.70	6.05
30: 192.06 72.96 358.39	377.69	11.18	356.29	4.93	21.40	7.29

Table 22: STS-128/17A VRCS Firing Statistics for APU Fuel Dump, RRR

Jet ID	Max-On (sec)		Firings			Total On-time (sec)		
	Avg.	Max.	Avg.	Max.	1 σ	Avg.	Max.	1 σ
F5L	58.28	79.68	13	40	9	172.49	294.64	43.81
F5R	39.20	99.04	7	23	4	92.16	242.08	41.66
L5D	220.16	276.88	149	330	57	2088.47	2213.68	44.19
L5L	8.46	22.56	32	76	15	32.58	60.64	11.91
R5D	274.72	344.96	58	135	23	2151.27	2267.28	36.91
R5R	12.41	23.84	15	57	13	27.27	60.32	10.75

Simulation results show that the DAP was able to maintain a reasonable level of attitude control throughout the 91 hp APU fuel dump for all of the configurations examined. Some runs did show transient attitude divergences outside the DAP’s attitude deadband. However, in all cases the divergence was a temporary event. Given the serious nature of the contingency and threat to crew safety if a dump were not performed, these attitude divergences are not sufficiently bad nor pervasive enough to disallow the procedure.

From a flight control perspective, nothing appeared in the Monte Carlo runs that would indicate that the DAP could not handle the 91 hp APU fuel leak scenario during nominal attitude hold near the TEA. Given the nature of the disturbance, it is crucial that other technical areas, such as ER for the robotics cases and ES for loads analysis, would need to concur before such a scenario could be approved. However, from an FCS standpoint, the scenario has been demonstrated to work when the attitude is near the TEA.

3.2.3 N₂ Vent for ATA Replacement

During STS-128, the P1 Ammonia Tank Assembly (ATA) will be replaced. As part of that procedure, it will be necessary to vent gaseous nitrogen from 2 tanks. The nominal procedure will be to issue ground commands for venting through a non-propulsive T-vent. If that fails, an EVA will be required, and the venting will be achieved through the use of a vent tool. Venting through the vent tool is propulsive, and the thrust direction is uncertain. Figure 3 is an example showing the thrust profile [10] and the resultant moments when the vent-force is in the +Z direction (Orbiter Body Axis System).

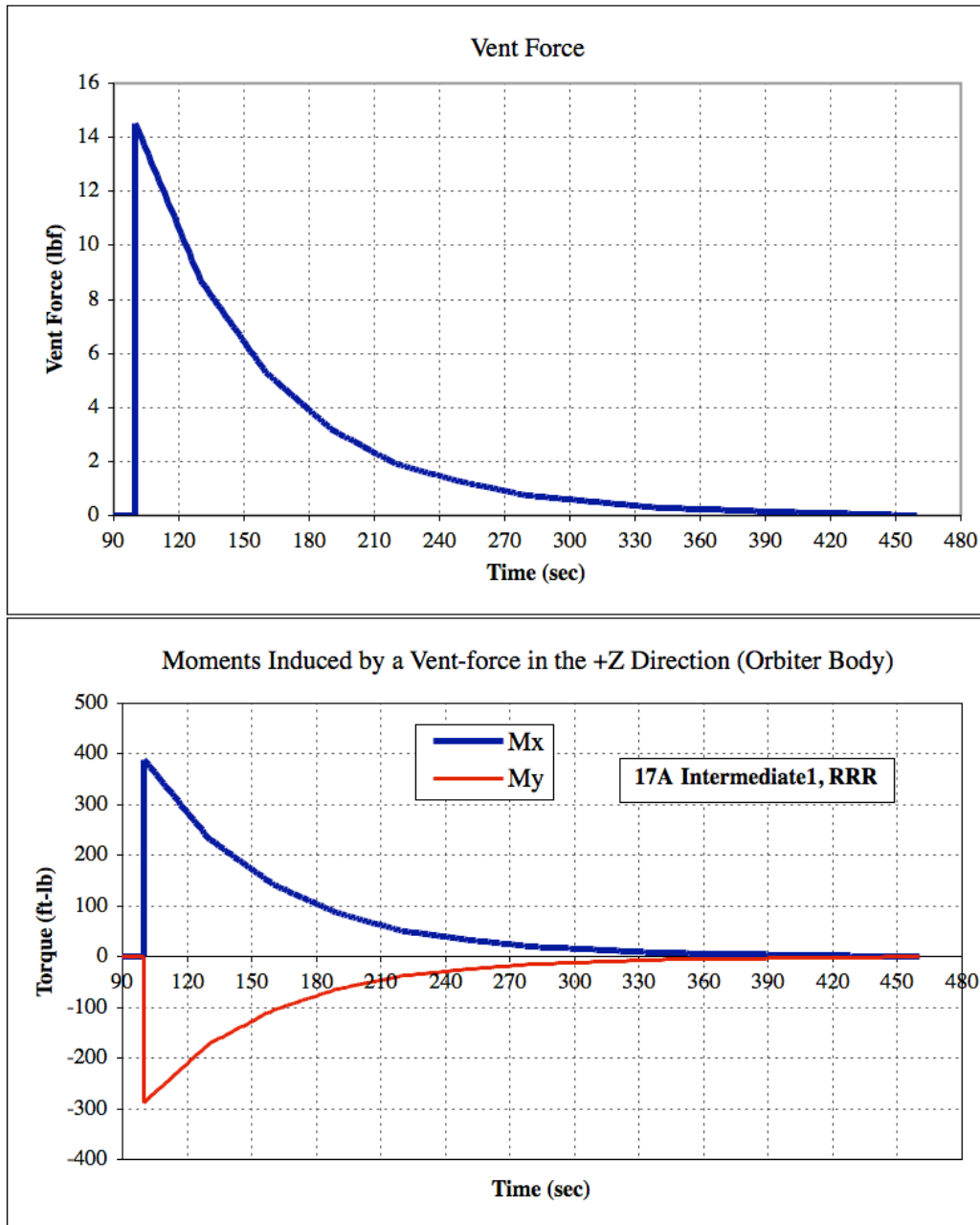


Figure 3: N₂ Venting Thrust Profile

If the T-vent is used, the primary expected source of attitude disturbance is from impingement of the expelled gas onto the surrounding truss structure. Data for the direction and magnitude of this disturbance is not available, but it is safe to assume that this disturbance would be of smaller magnitude than an unperturbed vent from the vent tool. Therefore it is sufficient to show that the control system can control during a worst case disturbance from the vent tool.

A series of VRCS attitude-hold simulations were run at the mated TEA, for a duration of 1 hour. The vehicle configuration is the Intermediate1 (post MPLM installation) phase. The vent disturbance begins at 100 seconds, and is over within about 6 minutes. The thrust was modeled in the plus and minus X, Y, and Z (Orbiter Body System) directions. The two worst case axes were also run with a doubled force magnitude. Figure 4 shows selected performance parameters from the simulations.

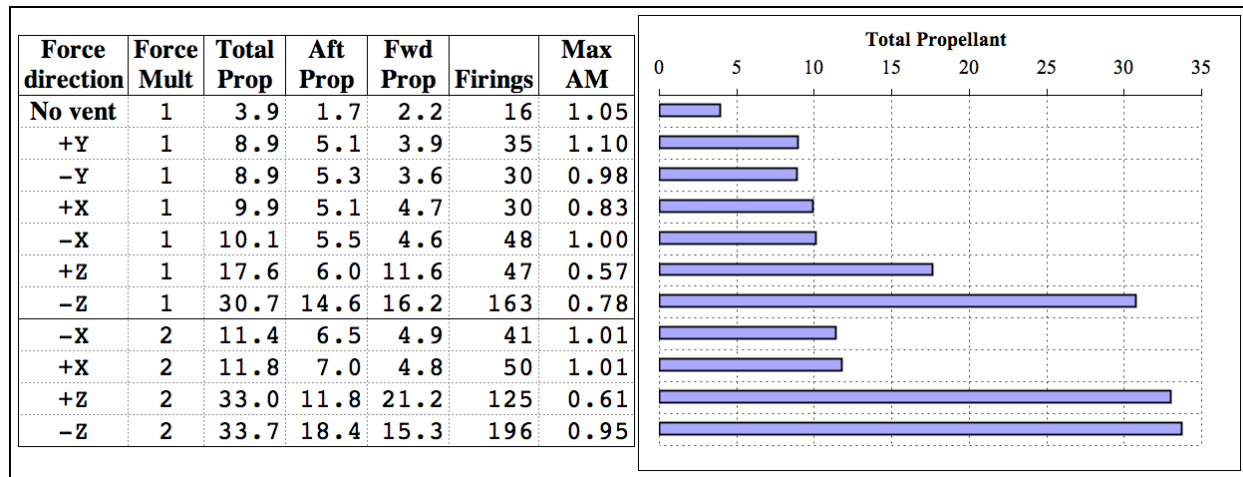


Figure 4: Vent Simulation Summary

The simulations used the Attitude-hold DAP, with attitude deadband of 1° and rate deadband of 0.02°/second. None of the simulations, including the the double-amplitude cases, had attitude or rate error excursions outside the phase plane. None had undesired acceleration magnitudes which exceeded half the relevant mag.control.accel values (Table 17 at the top of this section).

The Orbiter control is capable of maintaining attitude during the N₂ venting for STS-128. Since the results presented here represent a worst case analysis, as opposed to an assessment of an actual predicted disturbance, and because only a limited number of cases was run, the propellant data should not be assumed to be an accurate predictor of performance during the venting.

4 Robotics Operations

4.1 Overview

The Space Station RMS (SSRMS) is used for all major robotics operations on STS-128. The SSRMS is based on the Node 2 PDGF for the unberth of the MPLM from the Payload Bay, installation to the Node 2 nadir CBM and return to the Payload Bay.

Table 23: STS-128 SSRMS Position Nomenclature

	Joint Angles	Payload	SR	SY	SP	EP	WP	WY	WR
	STS-128/17A After Rendezvous	Non-Robotic Configuration							
MPLM Install	MPLM Grapple	MPLM-launch	74.6	175.4	-184.4	-86.6	-25.3	-62.3	119.4
	MPLM Low Hover	MPLM-launch	74.6	163.9	-134.5	-117.6	-60.2	-55.7	100.7
	MPLM Pre-Install	MPLM-launch	74.6	151.3	-188.3	-117.8	-126.5	-18.0	9.9
	MPLM Install	MPLM-launch	62.0	151.3	-203.3	-122.9	-113.0	-7.2	7.1
	STS-128/17A Intermediate 1	Non-Robotic Configuration							
	STS-128/17A Intermediate 2	Non-Robotic Configuration							
MPLM Return	MPLM Install	MPLM-landing	62.0	151.3	-203.3	-122.9	-113.0	-7.2	7.1
	MPLM Pre-Install	MPLM-landing	74.6	151.3	-188.3	-117.8	-126.5	-18.0	9.9
	MPLM Low Hover	MPLM-landing	74.6	163.9	-134.5	-117.6	-60.2	-55.7	100.7
	MPLM Grapple	MPLM-landing	74.6	175.4	-184.4	-86.6	-25.3	-62.3	119.4
	STS-128/17A Before Separation	Non-Robotic Configuration							

Shuttle control during loaded robotics operations is only allowed when the SSRMS is at one of the RMS positions [11] shown in Table 23 with either the brakes on or while in position hold mode. The greyed out lines in Table 23 indicate that DAP control is not allowed due to the RMS payload being too close to either the Shuttle or ISS. Only the VRCS maneuver DAP settings (A12) shown in Table 7 are allowed for the robotics operations. Shuttle control is not permitted at any time while the SSRMS is in motion and loaded with the MPLM.

During the EVA portion of the ATA SSRMS operations, the total mass on the SSRMS will remain less than 4,000 lbm. There is no generic SSRMS stability envelope, but based on engineering judgement and prior experience, we are considering all ATA operations as an unloaded arm for flight control purposes.

4.2 RMS Operations — DAP Constraints

- All non-RMS mated DAP constraints apply during loaded RMS operations.
- For loaded SSRMS operations, closed-loop DAP control is only allowed for the SSRMS positions in Table 23 using the standard mated maneuver VRCS DAP settings (A12) (see Table 7) with the SSRMS either with brakes on or in position hold mode.
- The following operations are not analyzed from an Orbiter flight control perspective during loaded SRMS, SSRMS, or JRMS operations, and are therefore not allowed:
 - ALT mode attitude control
 - Reboost (VRCS or ALT mode)
 - Propulsive venting through any of the Orbiter airlock hatch equalization valves
 - Propulsive venting for an APU fuel dump

5 Reboost

The reboost configurations for STS-128 were used previously for STS-126 and subsequent flights. For STS-128, there is one change to the settings – a rate deadband of $0.02^\circ/\text{sec}$ is required for the PRCS reboost.

There are only two distinct mated reboost modes — the standard VRCS and PRCS reboost modes from past flights. Configuration 1 is the only PRCS mated reboost, and is only to be used as backup due to reduced control authority with ALT. Configurations 3 and 4 contain identical I-Loads for VRCS reboost. Both mated reboost modes can be used to perform a deboost by using a different attitude. Configuration 2 is for contingency jettison of an un-crewed Orbiter and *is not certified for mated reboost*.

Table 24 outlines the basic mated reboost designs for STS-128. The related information for the non-mated reboost is shown in Table 25.

The DAP configuration for the unmanned Orbiter Separation and Disposal Procedure is defined in [12]. Note that many of the comments and constraints in this document regarding mated reboost do not apply for configuration 2.

Table 24: STS-128/17A Mated Reboost Design Summary

Cfg.	Pri.	Translation Jets								Rbst Interval (sec)	Jet Mode	Trans Delay (sec)		
		Type	Burn Time/Start Delay Time (sec)						F5R/L				R5D	L5D
			F2D	F1D	LXD	RXD								
1	2	-Z	0.08/0.0	0.08/6	0.08/12	0.08/18				24 ⁽¹⁾	ALT	12		
3	1	-Z					2 ⁽²⁾	2 ⁽²⁾	2 ⁽²⁾	2 ⁽²⁾	VRCS			
4	1	-Z					2 ⁽²⁾	2 ⁽²⁾	2 ⁽²⁾	2 ⁽²⁾	VRCS			

Notes:

1. For configuration 1, each of the four -Z jets is fired in sequence, separated by 6 seconds. The pattern is repeated every 24 seconds until the attitude or rate deadband is exceeded.
2. For configurations 3 and 4, the Reboost Interval is set to the Burn Time, resulting in a steady state VRCS firing until the attitude or rate deadband is exceeded.

Table 25: STS-128/17A Reboost Design Summary for Orbiter Disposal

Cfg.	Type	Translation Jets							Rbst Interval (sec)	Jet Mode	Trans Delay (sec)
		Burn Time/Start Delay Time (sec)									
		RXA	LXA	—	—	—	—	—			
2	+X	0.16/12.0	0.16/0.0						24.0	ALT	12

Table 26 contains the DAP configurations for all four reboost configurations. Specific DAP parameters are required for each of the reboost configurations to ensure stability and proper control during the reboost. Particular attention needs to be paid to the deadbands, rate limits, jet modes, and OAs associated with each reboost and ISS configuration.

Table 26: STS-128/17A Reboost DAP Configurations

Config	Translation	Rotation	OA	DB	RL	MR	Rbst Intvl	Alt Dly	Alt Opt	Alt #	LowZ	Xjets
1	-Z	Alt	OA2 or OA4	10	0.02	0.05	24.0	7.04	Tail	1	on	disabled
2	+X	Alt	OMI 2.01	2	0.1	0.5	24.0	0	ALL	2	off	disabled
3	VRCS	Vern	OA2 or OA4	5	0.05	0.10	2.0	n/a	n/a	n/a	n/a	n/a
4	VRCS	Vern	OA2 or OA4	5	0.05	0.10	2.0	n/a	n/a	n/a	n/a	n/a

For each vehicle configuration, 1,000 Monte Carlo cases were run for PRCS and VRCS mated reboosts as well as deboosts. Mass property dispersions of $\pm 10\%$ in inertia and ± 6 inches in center of mass, initial rate error dispersions of ± 0.01 deg/sec, and modal uncertainties of ± 4 dB in amplitude and $\pm 20\%$ in frequency were applied to each of the cases.

For the PRCS mated reboost, an attitude deadband of 10° and a rate deadband of $0.02^\circ/\text{sec}$ are required. The jet control mode must be configured to LowZ (via PBI) with X jets *disabled* (via DAP CONFIG page), and, as with the nominal ALT mode, the forward Y jets deselected. Furthermore, the ALT DAP must be set to 1-jet with 7.04 second delays. Since control authority with ALT is limited, large attitude excursions from the reboost attitude were occasionally seen in simulations for past flights. For such cases, the flight rules state that the reboost is to be terminated when the attitude error reaches twice the deadband. For STS-128, the reduced rate limit of $0.02^\circ/\text{sec}$ provides tighter control, and no attitude exceedances larger than twice the deadband were observed in simulations for the attitudes in Tables 27 and 28. The maximum attitude exceedances are shown in Tables 29 and 30.

For the VRCS controlled reboost, the required attitude and rate deadbands are 5.0° and $0.05^\circ/\text{sec}$ respectively. The normal VRCS control mode is used for reboost, so unlike the PRCS modes, no special jet re-configuration is required. Attitude errors from VRCS reboost simulations remained below 9 degrees in pitch, and below 6 degrees in roll and yaw.

The reboost and deboost efficiencies per the defined configurations are given in Tables 27 and 28. The Orbiter body attitude relative to LVLH is expressed by a PYR Euler angle sequence given in RPY order. Particular attention should be given to the boost attitudes shown. For PRCS, the boost attitudes are TEAs. PRCS boost at other attitudes can lead to significant attitude excursions exceeding twice the attitude deadband, in violation of the flight rule. For VRCS, the optimal boost attitude that aligns the resultant thrust vector from the translational and rotational firings is shown. Attitude offsets are required in Orbiter pitch and roll (ISS pitch and yaw) in order to align the thrust vector correctly and thereby maximize the ΔV along the LVLH +X axis. Failure to conform to these attitudes may result in thrust misalignment and reduce the net ΔV along the LVLH +X axis.

Section 5.1 lists the reboost constraints. Sections 5.2 and 5.3 give a summary of expected thruster firings (Tables 31 and 32) and sample plots (Figures 5 through 8) for each reboost configuration.

Table 27: STS-128 Reboost Efficiencies and Attitudes

Configuration		ΔV_x	Time	Propellant (lbs/hr)			Prop per ΔV_x (lbs/(ft/sec))			Orbiter Attitude (deg)		
#	Type	(ft/sec/hr)	(hr/(ft/sec))	Total	Fwd	Aft	Total	Fwd	Aft	R	P	Y
Intermediate1 RRR												
1	-Z ALT	0.775	1.291	141	94	47	183	121	61	180	73	0.0
3/4	VRCS	5.861	0.171	982	612	371	168	104	63	-176	86	-0.3
Intermediate1 RRx												
1	-Z ALT	0.782	1.280	142	94	48	181	120	62	180	71	0.0
3/4	VRCS	5.961	0.168	991	618	374	166	104	63	-176	86	-0.3
Intermediate1 RxR												
1	-Z ALT	0.782	1.279	142	94	47	181	120	61	180	71	0.0
3/4	VRCS	5.904	0.169	972	611	361	165	104	61	-176	86	-0.3
Intermediate1 RRR HTV												
1	-Z ALT	0.745	1.342	138	102	37	186	136	50	180	80	0.0
3/4	VRCS	5.581	0.179	960	609	350	172	109	63	-178	86	-0.1
Intermediate1 RRx HTV												
1	-Z ALT	0.755	1.325	139	102	36	184	136	48	180	80	0.0
3/4	VRCS	5.663	0.177	961	610	352	170	108	62	-178	86	-0.1
Intermediate1 RxR HTV												
1	-Z ALT	0.755	1.324	138	103	35	183	137	46	180	80	0.0
3/4	VRCS	5.607	0.178	945	605	340	169	108	61	-178	86	-0.1
Final RRR												
1	-Z ALT	0.776	1.289	141	94	47	182	121	61	180	73	0.0
3/4	VRCS	5.891	0.170	990	610	380	168	104	64	-176	86	-0.3
Final RRx												
1	-Z ALT	0.784	1.275	142	94	48	181	120	61	180	71	0.0
3/4	VRCS	5.986	0.167	1000	618	382	167	103	64	-176	86	-0.3
Final RxR												
1	-Z ALT	0.782	1.279	141	94	48	181	120	61	180	71	0.0
3/4	VRCS	5.925	0.169	984	615	369	166	104	62	-176	86	-0.3
Final RRR HTV												
1	-Z ALT	0.743	1.347	138	103	35	186	138	47	180	81	0.0
3/4	VRCS	5.618	0.178	957	599	358	170	107	64	-178	86	-0.1
Final RRx HTV												
1	-Z ALT	0.757	1.322	138	103	35	183	137	46	180	81	0.0
3/4	VRCS	5.689	0.176	971	612	359	171	108	63	-178	86	-0.1
Final RxR HTV												
1	-Z ALT	0.753	1.328	138	104	33	183	139	44	180	81	0.0
3/4	VRCS	5.638	0.177	953	606	347	169	108	62	-178	86	-0.1

Table 28: STS-128 Deboost Efficiencies and Attitudes

Configuration		ΔV_x	Time	Propellant (lbs/hr)			Prop per ΔV_x (lbs/(ft/sec))			Orbiter Attitude (deg)		
#	Type	(ft/sec/hr)	(hr/(ft/sec))	Total	Fwd	Aft	Total	Fwd	Aft	R	P	Y
Intermediate1 RRR												
1	-Z ALT	-0.778	1.285	143	93	50	184	119	64	0	107	0.0
3/4	VRCS	-5.778	0.173	978	613	365	169	106	63	3	94	0.2
Intermediate1 RRx												
1	-Z ALT	-0.787	1.271	143	93	50	182	118	64	0	109	0.0
3/4	VRCS	-5.872	0.170	981	615	367	167	105	62	3	94	0.2
Intermediate1 RxR												
1	-Z ALT	-0.786	1.273	143	93	49	182	119	63	0	109	0.0
3/4	VRCS	-5.824	0.172	968	613	354	166	105	61	3	94	0.2
Intermediate1 RRR HTV												
1	-Z ALT	-0.768	1.302	142	103	39	185	134	50	0	99	0.0
3/4	VRCS	-5.474	0.183	952	606	346	174	111	63	3	94	0.2
Intermediate1 RRx HTV												
1	-Z ALT	-0.783	1.277	142	105	38	182	133	48	0	99	0.0
3/4	VRCS	-5.555	0.180	954	606	348	172	109	63	3	94	0.2
Intermediate1 RxR HTV												
1	-Z ALT	-0.781	1.281	142	105	37	182	135	47	0	99	0.0
3/4	VRCS	-5.499	0.182	943	607	336	172	111	61	3	94	0.2
Final RRR												
1	-Z ALT	-0.780	1.283	143	93	50	183	119	64	0	107	0.0
3/4	VRCS	-5.827	0.172	987	615	373	170	106	64	3	94	0.2
Final RRx												
1	-Z ALT	-0.788	1.268	143	93	50	181	118	64	0	109	0.0
3/4	VRCS	-5.910	0.169	989	615	374	167	104	63	3	94	0.2
Final RxR												
1	-Z ALT	-0.787	1.271	143	93	50	181	118	63	0	109	0.0
3/4	VRCS	-5.854	0.171	976	615	362	167	105	62	3	94	0.2
Final RRR HTV												
1	-Z ALT	-0.769	1.300	142	103	38	185	135	50	0	99	0.0
3/4	VRCS	-5.505	0.182	959	606	352	174	110	64	3	94	0.2
Final RRx HTV												
1	-Z ALT	-0.786	1.273	142	105	38	181	133	48	0	99	0.0
3/4	VRCS	-5.580	0.179	962	608	354	172	109	63	3	94	0.2
Final RxR HTV												
1	-Z ALT	-0.782	1.279	142	106	37	182	135	47	0	99	0.0
3/4	VRCS	-5.529	0.181	948	606	342	172	110	62	3	94	0.2

Table 29: STS-128 ALT Reboost Attitude Exceedances

Config.	Visiting Vehicles	Max Attitude Error (deg)			% of Cases > 2×DB
		Roll	Pitch	Yaw	
Intermediate1	RRR	11.20	13.06	12.53	0.0
Intermediate1	RRx	11.03	12.26	11.86	0.0
Intermediate1	RxR	11.22	12.46	12.02	0.0
Intermediate1	RRR HTV	11.01	13.94	11.41	0.0
Intermediate1	RRx HTV	10.97	14.39	11.69	0.0
Intermediate1	RxR HTV	11.03	14.40	11.65	0.0
Final	RRR	10.97	13.90	11.89	0.0
Final	RRx	11.03	12.12	12.26	0.0
Final	RxR	10.92	12.40	11.94	0.0
Final	RRR HTV	11.07	14.32	11.42	0.0
Final	RRx HTV	11.15	13.99	11.45	0.0
Final	RxR HTV	11.19	16.54	11.07	0.0

Table 30: STS-128 ALT Deboost Attitude Exceedances

Config.	Visiting Vehicles	Max Attitude Error (deg)			% of Cases > 2×DB
		Roll	Pitch	Yaw	
Intermediate1	RRR	15.02	12.20	13.84	0.0
Intermediate1	RRx	14.45	11.44	12.79	0.0
Intermediate1	RxR	13.52	11.82	12.74	0.0
Intermediate1	RRR HTV	10.63	12.11	12.85	0.0
Intermediate1	RRx HTV	10.64	11.70	11.71	0.0
Intermediate1	RxR HTV	10.63	12.37	12.05	0.0
Final	RRR	14.76	11.96	13.26	0.0
Final	RRx	15.04	11.31	12.74	0.0
Final	RxR	14.23	12.30	12.65	0.0
Final	RRR HTV	10.71	12.52	12.86	0.0
Final	RRx HTV	10.66	11.64	11.84	0.0
Final	RxR HTV	10.69	12.57	11.81	0.0

5.1 Reboost Constraints

- Reboost constraints documented in the Flight Rules
 - Auto reboost modes that utilize the VRCS are limited to a duration of 1 hour and an interval between reboost events of at least 20 hours. There is an additional limit of no more than 3 hours cumulative VRCS reboost per mission.
 - There shall be a 5-minute pause between the end of the maneuver to reboost attitude and the initiation of reboost.
 - Reboost will be terminated if it is observed that attitude errors exceed two times the attitude deadband.
 - The orbiter airlock must be pressurized to a minimum of 3.45 psi prior to reboost.
 - Water dumps, propulsive venting and APU burn-offs are prohibited during reboost.
 - Reboost is not allowed during loaded SRMS, SSRMS, or JEM RMS operations.
 - To avoid IMU ID switching, an IMU will be deselected for the reboost.
 - The cycle ergonometer is limited to a maximum of 67.5 RPM during reboosts using config 1.
- Additional assumptions/constraints
 - Automatic reboost is only certified for the configurations as documented in this memo.
 - Automatic reboost is robust to changes in mass properties for the flight. However control acceleration selections should follow along with mass property configuration and active jet mode. Proper OA selection insures accuracy in DAP feedforward and notch filtering.
 - No attitude maneuvers can be performed while automatic reboost is active.
 - Both the reboost translation and DAP rotation mode must be configured as described for the established reboost mode.
 - High data rate during reboost operations is highly desirable.
 - Downlist of undesired acceleration during reboost is highly desirable.

5.2 Config 1 Reboost, -Z ALT, Jet Firing Statistics and Sample Plots

Table 31: Config 1, -Z ALT Jet Firing Statistics

Jet ID	Total On-time (sec)		
	Avg.	Max.	1σ
Final RRR			
F1D	13.87	16.48	1.29
F2D	15.50	18.08	1.27
L1L	0.24	3.20	0.47
L2D	7.27	11.20	0.82
R1R	0.84	2.88	0.58
R2D	7.35	12.88	0.99
Final RRR HTV			
F1D	15.73	17.76	0.89
F2D	16.94	19.60	0.89
L1L	0.14	2.48	0.36
L2D	5.54	7.28	0.54
R1R	0.92	3.60	0.56
R2D	5.54	7.44	0.54

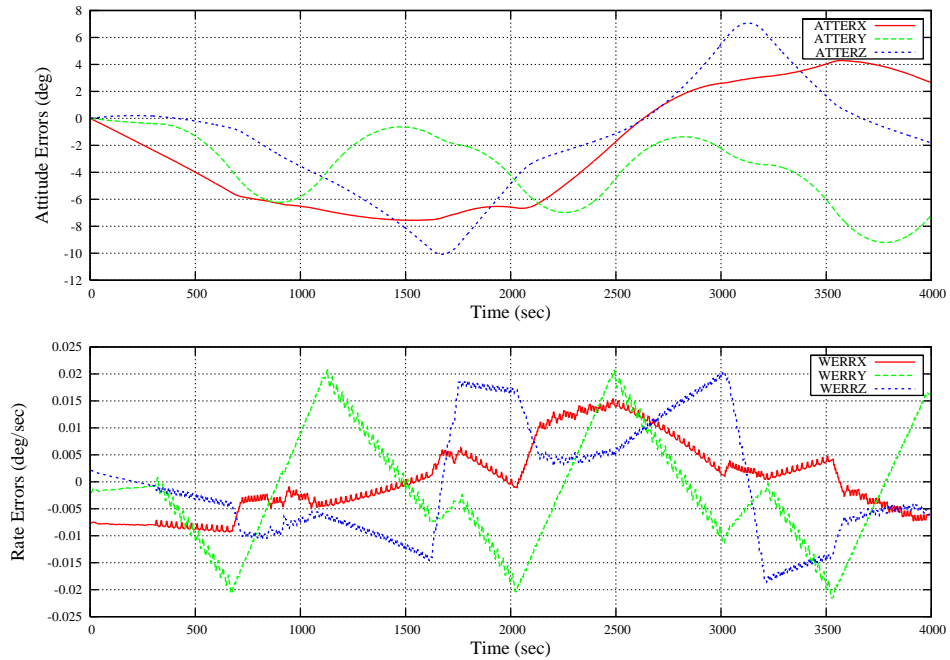


Figure 5: Config 1 Reboost, -Z ALT, Attitude and Rate Errors

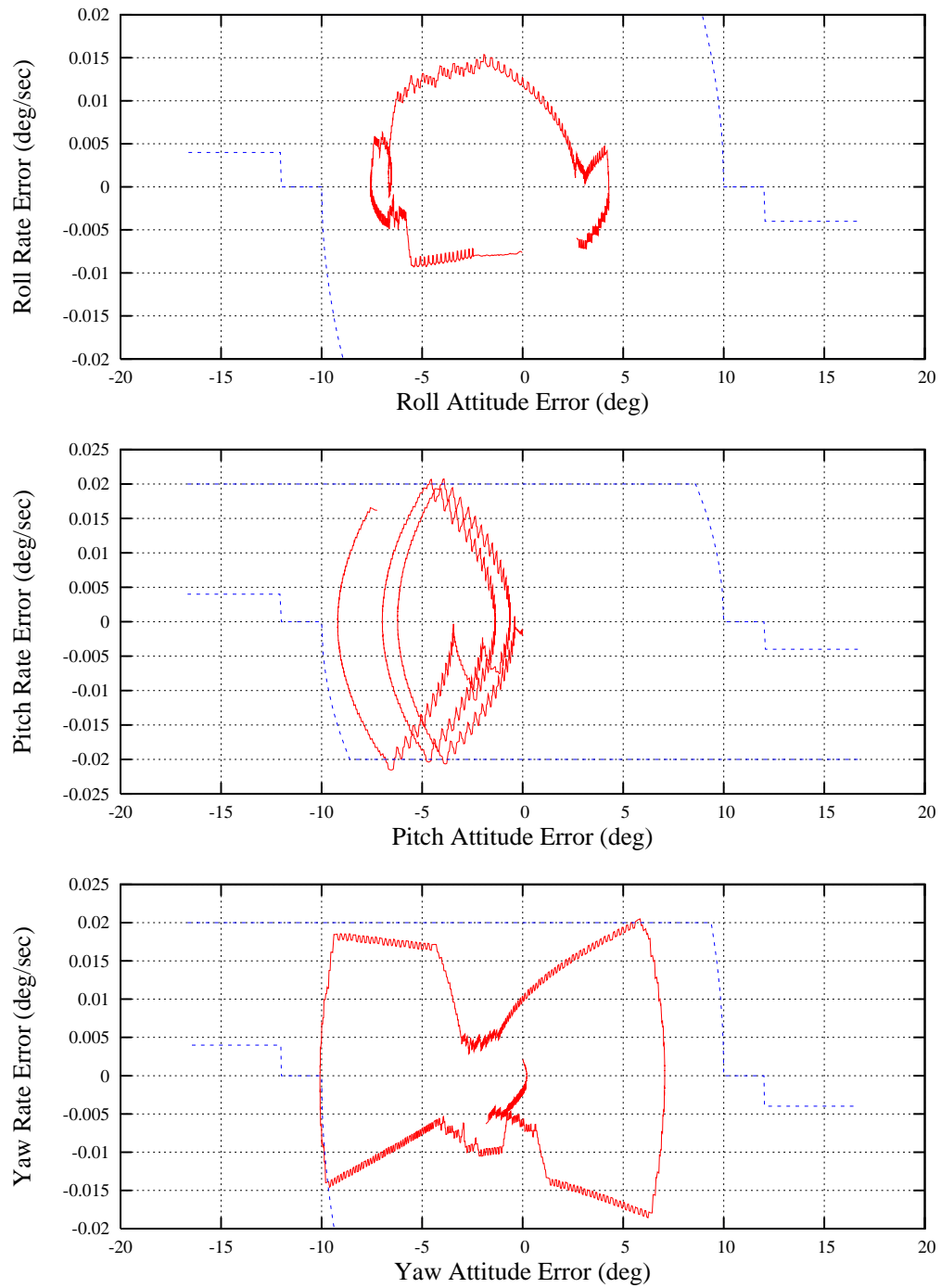


Figure 6: Config 1 Reboost, -Z ALT, Phase Planes

5.3 Config 3/4 Reboost, VRCS, Jet Firing Statistics and Sample Plots

Table 32: Config 3/4, VRCS Jet Firing Statistics

Jet ID	Max-On (sec)		Firings			Total On-time (sec)		
	Avg.	Max.	Avg.	Max.	1σ	Avg.	Max.	1σ
Final RRR								
F5L	1068.63	1546.40	53	191	36	3181.88	3429.60	118.19
F5R	1655.49	3685.28	18	185	27	3487.22	3715.20	319.98
L5D	252.15	306.64	35	210	29	1898.18	2101.92	69.95
L5L	15.92	41.28	23	224	30	36.22	166.48	33.45
R5D	255.09	344.00	53	257	38	1967.67	2148.32	74.99
R5R	26.31	50.08	125	398	55	135.03	262.64	37.11
Final RRR HTV								
F5L	1040.90	1605.52	64	205	40	3143.06	3424.40	145.77
F5R	1441.56	3688.16	34	244	42	3434.11	3689.28	268.19
L5D	235.91	283.44	34	187	28	1784.05	1956.00	69.73
L5L	18.49	45.28	34	211	36	46.64	177.04	34.75
R5D	238.43	329.36	48	249	38	1849.46	2089.04	78.03
R5R	27.66	54.24	140	431	66	138.24	270.96	39.36

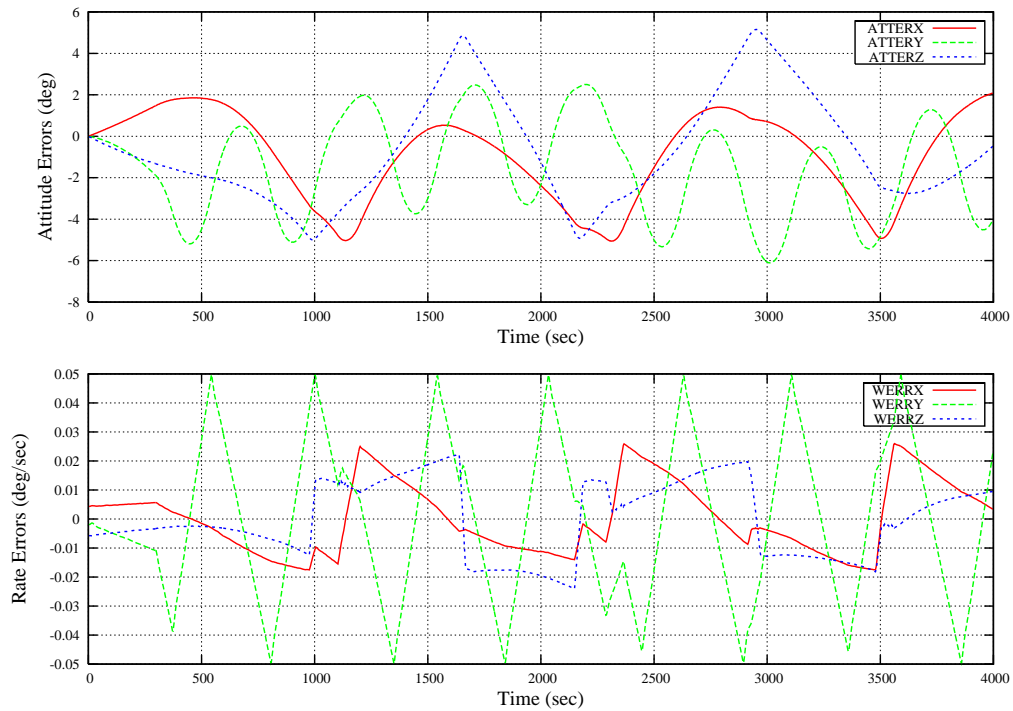


Figure 7: Config 3/4 Reboost, VRCS, Attitude and Rate Errors

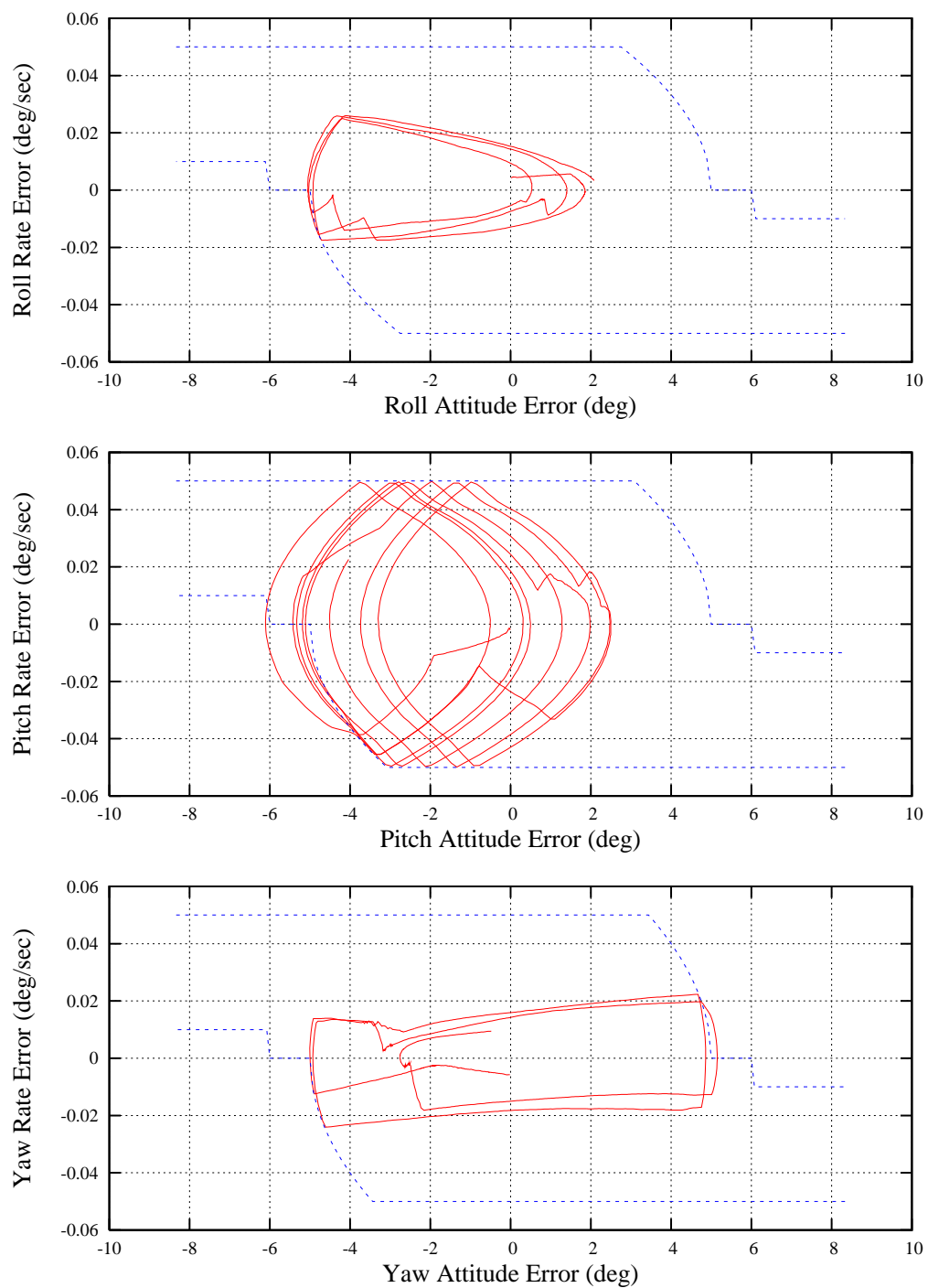


Figure 8: Config 3/4 Reboost, VRCS, Phase Planes

5.4 Reboost/Deboost via Attitude Hold

Reboosts and deboosts can also be achieved without activating the reboost logic by performing a long-term attitude hold. Like the mission specific attitude holds, 100 attitude holds of duration 22,000 sec were run for various ISS attitudes with dispersed mass properties ($\pm 1\%$ in inertia, ± 6 inches in center of mass), initial rate errors ($\pm 0.01^\circ/\text{sec}$), and modal uncertainties ($\pm 4\text{dB}$ amplitude, $\pm 20\%$ frequency). The attitudes included TEAs based on the July 22 Final ATL, the boost design attitudes given in Tables 27 and 28, as well as the LVLH-aligned attitudes for $+XVV$ and $-XVV$. Tables 33 and 34 show the average ΔV from holding attitude for reboost and deboost respectively. The Orbiter body attitude relative to LVLH is expressed by a PYR Euler angle sequence given in RPY order. Note that holding attitude at LVLH with ALT yields ΔV_x in the opposite direction as desired (shown in red). Tables 35 and 36 show the propellant usage for the attitude holds.

Table 33: Estimated ΔV for reboost using attitude hold for RRR

Attitude	ΔV_x	ΔV_y	ΔV_z	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
	(ft/sec/hr)	(ft/sec/hr)	(ft/sec/hr)		Total	Fwd	Aft
Intermediate1 RRR (Hold DAP) – ATL TEA: 170.99 73.55 4.80							
ALT lzxnfy-1	0.005	-0.001	0.016	206.401	1547	976	571
VRCS	0.024	0.005	0.006	41.396	212	106	106
Intermediate1 RRR (Hold DAP) – Design: 180 73 0							
ALT lzxnfy-1	0.008	0.007	0.019	130.775	959	657	302
Intermediate1 RRR (Hold DAP) – Design: -176 86 -0.28							
VRCS	0.251	-0.000	0.023	3.990	157	149	9
Intermediate1 RRR (Hold DAP) – LVLH: 180 90 0							
ALT lzxnfy-1	-0.008	0.004	-0.127	119.922	2528	358	2170
VRCS	0.317	0.021	0.007	3.150	156	149	7
Final RRR (Hold DAP) – ATL TEA: 170.91 74.54 4.64							
ALT lzxnfy-1	0.010	-0.000	-0.004	98.967	546	215	332
VRCS	0.039	0.007	0.011	25.764	187	146	41
Final RRR (Hold DAP) – Design: 180 73 0							
ALT lzxnfy-1	0.010	0.007	0.014	101.957	673	432	241
Final RRR (Hold DAP) – Design: -176 86 -0.28							
VRCS	0.261	-0.000	0.023	3.837	157	148	9
Final RRR (Hold DAP) – LVLH: 180 90 0							
ALT lzxnfy-1	-0.009	0.004	-0.133	105.389	2324	317	2007
VRCS	0.328	0.022	0.007	3.051	156	149	7

Intermediate1 RRR (Maneuver DAP) – ATL TEA: 170.99 73.55 4.80							
VRCS	0.070	0.015	0.016	14.354	212	114	98
Intermediate1 RRR (Maneuver DAP) – Design: -176 86 -0.28							
VRCS	0.268	0.001	0.015	3.738	164	145	18
Intermediate1 RRR (Maneuver DAP) – LVLH: 180 90 0							
VRCS	0.330	0.024	-0.004	3.031	161	147	14
Final RRR (Maneuver DAP) – ATL TEA: 170.91 74.54 4.64							
VRCS	0.075	0.015	0.018	13.285	206	123	82
Final RRR (Maneuver DAP) – Design: -176 86 -0.28							
VRCS	0.276	0.001	0.015	3.627	163	146	18
Final RRR (Maneuver DAP) – LVLH: 180 90 0							
VRCS	0.338	0.024	-0.004	2.960	161	147	13

Note: Rows shown in red yield negative ΔV_x (i.e., a deboost).

Table 34: Estimated ΔV for deboost using attitude hold for RRR

Attitude	ΔV_x	ΔV_y	ΔV_z	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
	(ft/sec/hr)	(ft/sec/hr)	(ft/sec/hr)		Total	Fwd	Aft
Intermediate1 RRR (Hold DAP) – ATL TEA: -9.01 106.45 -4.80							
ALT lzxnfy-1	-0.019	-0.003	0.027	53.786	590	404	185
VRCS	-0.026	-0.005	0.006	38.277	210	110	101
Intermediate1 RRR (Hold DAP) – Design: 0 107 0							
ALT lzxnfy-1	-0.016	-0.008	0.026	63.888	647	456	191
Intermediate1 RRR (Hold DAP) – Design: 3 94 0.21							
VRCS	-0.262	-0.005	0.023	3.823	158	148	10
Intermediate1 RRR (Hold DAP) – LVLH: 0 90 0							
ALT lzxnfy-1	0.002	-0.004	-0.126	448.851	100531	18702	81830
VRCS	-0.334	-0.023	0.006	2.993	157	147	9
Final RRR (Hold DAP) – ATL TEA: -9.09 105.46 -4.64							
ALT lzxnfy-1	-0.022	-0.004	0.009	44.758	434	254	180
VRCS	-0.043	-0.008	0.013	23.177	188	145	42
Final RRR (Hold DAP) – Design: 0 107 0							
ALT lzxnfy-1	-0.017	-0.008	0.020	59.017	542	366	176
Final RRR (Hold DAP) – Design: 3 94 0.21							
VRCS	-0.271	-0.005	0.024	3.689	157	147	10
Final RRR (Hold DAP) – LVLH: 0 90 0							
ALT lzxnfy-1	0.005	-0.004	-0.134	197.547	31440	5939	25502
VRCS	-0.343	-0.024	0.007	2.913	157	147	9

Intermediate1 RRR (Maneuver DAP) – ATL TEA: -9.01 106.45 -4.80							
VRCS	-0.069	-0.016	0.017	14.548	209	114	95
Intermediate1 RRR (Maneuver DAP) – Design: 3 94 0.21							
VRCS	-0.269	-0.005	0.016	3.723	163	146	17
Intermediate1 RRR (Maneuver DAP) – LVLH: 0 90 0							
VRCS	-0.335	-0.026	-0.003	2.981	161	148	14
Final RRR (Maneuver DAP) – ATL TEA: -9.09 105.46 -4.64							
VRCS	-0.080	-0.017	0.019	12.560	201	122	79
Final RRR (Maneuver DAP) – Design: 3 94 0.21							
VRCS	-0.277	-0.006	0.016	3.604	163	146	17
Final RRR (Maneuver DAP) – LVLH: 0 90 0							
VRCS	-0.343	-0.026	-0.003	2.916	161	147	13

Note: Rows shown in red yield positive ΔV_x (i.e., a reboost).

Table 35: Estimated propellant usage for reboost using attitude hold for RRR

Attitude	Total (lbs/hr)	1 σ (lbs/hr)	Aft (lbs/hr)	1 σ (lbs/hr)	Fwd (lbs/hr)	1 σ (lbs/hr)
Intermediate1 RRR (Hold DAP) – ATL TEA: 170.99 73.55 4.80						
ALT lzxnfy-1	5.96	0.57	2.22	0.28	3.74	0.58
VRCS	5.11	0.64	2.56	0.52	2.55	0.48
Intermediate1 RRR (Hold DAP) – Design: 180 73 0						
ALT lzxnfy-1	6.89	0.53	2.19	0.28	4.69	0.53
Intermediate1 RRR (Hold DAP) – Design: -176 86 -0.28						
VRCS	39.43	0.92	2.22	0.33	37.22	0.68
Intermediate1 RRR (Hold DAP) – LVLH: 180 90 0						
ALT lzxnfy-1	20.34	0.37	17.50	0.26	2.84	0.26
VRCS	49.56	1.31	2.34	0.46	47.22	0.95
Final RRR (Hold DAP) – ATL TEA: 170.91 74.54 4.64						
ALT lzxnfy-1	5.43	0.45	3.28	0.41	2.16	0.39
VRCS	7.25	0.85	1.56	0.33	5.69	0.81
Final RRR (Hold DAP) – Design: 180 73 0						
ALT lzxnfy-1	6.34	0.41	2.29	0.29	4.04	0.47
Final RRR (Hold DAP) – Design: -176 86 -0.28						
VRCS	40.91	0.94	2.28	0.37	38.63	0.72
Final RRR (Hold DAP) – LVLH: 180 90 0						
ALT lzxnfy-1	21.23	0.38	18.37	0.23	2.86	0.28
VRCS	51.10	1.34	2.43	0.49	48.67	0.97

Intermediate1 RRR (Maneuver DAP) – ATL TEA: 170.99 73.55 4.80						
VRCS	14.75	2.33	6.84	1.23	7.91	1.34
Intermediate1 RRR (Maneuver DAP) – Design: -176 86 -0.28						
VRCS	43.85	2.00	4.96	0.84	38.89	1.31
Intermediate1 RRR (Maneuver DAP) – LVLH: 180 90 0						
VRCS	53.14	2.05	4.55	0.74	48.58	1.43
Final RRR (Maneuver DAP) – ATL TEA: 170.91 74.54 4.64						
VRCS	15.45	2.12	6.20	1.06	9.25	1.26
Final RRR (Maneuver DAP) – Design: -176 86 -0.28						
VRCS	45.03	2.11	4.85	0.87	40.18	1.37
Final RRR (Maneuver DAP) – LVLH: 180 90 0						
VRCS	54.29	2.11	4.51	0.82	49.78	1.41

Note: Rows shown in red yield negative ΔV_x (i.e., a deboost).

Table 36: Estimated propellant usage for deboost using attitude hold for RRR

Attitude	Total (lbs/hr)	1 σ (lbs/hr)	Aft (lbs/hr)	1 σ (lbs/hr)	Fwd (lbs/hr)	1 σ (lbs/hr)
Intermediate1 RRR (Hold DAP) – ATL TEA: -9.01 106.45 -4.80						
ALT lzxnfy-1	10.78	1.14	3.40	0.39	7.38	0.84
VRCS	5.49	0.62	2.62	0.40	2.87	0.51
Intermediate1 RRR (Hold DAP) – Design: 0 107 0						
ALT lzxnfy-1	9.88	1.15	2.93	0.39	6.95	0.82
Intermediate1 RRR (Hold DAP) – Design: 3 94 0.21						
VRCS	41.26	1.18	2.63	0.37	38.63	0.90
Intermediate1 RRR (Hold DAP) – LVLH: 0 90 0						
ALT lzxnfy-1	21.91	0.86	18.07	0.31	3.84	0.63
VRCS	52.44	1.26	3.18	0.36	49.27	1.00
Final RRR (Hold DAP) – ATL TEA: -9.09 105.46 -4.64						
ALT lzxnfy-1	9.63	0.92	3.98	0.37	5.65	0.66
VRCS	8.08	1.01	1.80	0.28	6.27	0.95
Final RRR (Hold DAP) – Design: 0 107 0						
ALT lzxnfy-1	9.06	1.26	2.95	0.37	6.11	1.00
Final RRR (Hold DAP) – Design: 3 94 0.21						
VRCS	42.69	1.11	2.75	0.39	39.95	0.83
Final RRR (Hold DAP) – LVLH: 0 90 0						
ALT lzxnfy-1	22.53	0.72	18.90	0.29	3.63	0.57
VRCS	53.85	1.27	3.27	0.43	50.58	0.97

Intermediate1 RRR (Maneuver DAP) – ATL TEA: -9.01 106.45 -4.80						
VRCS	14.34	2.44	6.56	1.36	7.78	1.32
Intermediate1 RRR (Maneuver DAP) – Design: 3 94 0.21						
VRCS	43.90	1.77	4.68	0.70	39.23	1.22
Intermediate1 RRR (Maneuver DAP) – LVLH: 0 90 0						
VRCS	54.07	1.98	4.58	0.78	49.49	1.36
Final RRR (Maneuver DAP) – ATL TEA: -9.09 105.46 -4.64						
VRCS	16.04	2.36	6.31	1.19	9.72	1.35
Final RRR (Maneuver DAP) – Design: 3 94 0.21						
VRCS	45.13	1.96	4.63	0.84	40.50	1.24
Final RRR (Maneuver DAP) – LVLH: 0 90 0						
VRCS	55.06	1.98	4.53	0.74	50.53	1.38

Note: Rows shown in red yield positive ΔV_x (i.e., a reboost).

5.5 Maneuvers to and from Reboost/Deboost Attitudes

Maneuvers to the reboost/deboost attitudes and back were simulated to provide estimates of the resulting ΔV and propellant usage. 100 cases were run for each maneuver with dispersed mass properties ($\pm 1\%$ in inertia, ± 6 inches in center of mass), initial rate errors ($\pm 0.01^\circ/\text{sec}$), and modal uncertainties ($\pm 4\text{dB}$ amplitude, $\pm 20\%$ frequency). Tables 37 through 40 show the average ΔV from the maneuvers and Tables 41 through 44 show the propellant usage. The tables show the Orbiter body attitude relative to LVLH which is expressed by a PYR Euler angle sequence given in RPY order. The simulation duration was 3600 sec.

Table 37: Estimated ΔV for maneuvers to and from reboost for Intermediate1 RRR

Attitude	ΔV_x (ft/sec)	ΔV_y (ft/sec)	ΔV_z (ft/sec)	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
					Total	Fwd	Aft
Mnvr to Reboost: -9.01 106.45 -4.80:170.99 73.55 4.80							
VRCS	0.073	0.016	0.219	13.646	7617	5228	2388
Mnvr to Reboost: 170.99 73.55 4.80:180 90 0							
VRCS	0.705	0.085	0.009	1.419	178	126	51
Mnvr to Reboost: 170.99 73.55 4.80:-176 86 -0.28							
VRCS	0.578	0.052	0.055	1.730	190	127	63
Mnvr to Reboost: -9.01 106.45 -4.80:180 90 0							
VRCS	0.221	-0.036	0.099	4.523	884	645	240
Mnvr to Reboost: -9.01 106.45 -4.80:-176 86 -0.28							
VRCS	0.145	-0.058	0.134	6.899	1408	1013	396
Mnvr from Reboost: 170.99 73.55 4.80:-9.01 106.45 -4.80							
VRCS	-0.086	-0.011	0.163	11.577	2297	936	1361
Mnvr from Reboost: 180 90 0:170.99 73.55 4.80							
VRCS	0.419	0.061	0.040	2.389	199	111	89
Mnvr from Reboost: -176 86 -0.28:170.99 73.55 4.80							
VRCS	0.392	0.047	0.060	2.551	215	114	101
Mnvr from Reboost: 180 90 0:-9.01 106.45 -4.80							
VRCS	-0.069	0.062	0.046	14.490	4603	1931	2671
Mnvr from Reboost: -176 86 -0.28:-9.01 106.45 -4.80							
VRCS	-0.054	0.053	0.071	18.420	4034	1700	2334

Table 38: Estimated ΔV for maneuvers to and from reboost for Final RRR

Attitude	ΔV_x (ft/sec)	ΔV_y (ft/sec)	ΔV_z (ft/sec)	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
					Total	Fwd	Aft
Mnvr to Reboost: -9.09 105.46 -4.64:170.91 74.54 4.64							
VRCS	0.094	0.012	0.218	10.673	27392	19106	8286
Mnvr to Reboost: 170.91 74.54 4.64:180 90 0							
VRCS	0.706	0.078	0.009	1.416	179	126	53
Mnvr to Reboost: 170.91 74.54 4.64:-176 86 -0.28							
VRCS	0.560	0.051	0.053	1.784	192	128	64
Mnvr to Reboost: -9.09 105.46 -4.64:180 90 0							
VRCS	0.231	-0.044	0.093	4.328	823	595	227
Mnvr to Reboost: -9.09 105.46 -4.64:-176 86 -0.28							
VRCS	0.184	-0.066	0.130	5.446	1239	890	349
Mnvr from Reboost: 170.91 74.54 4.64:-9.09 105.46 -4.64							
VRCS	-0.101	-0.028	0.150	9.900	1863	763	1100
Mnvr from Reboost: 180 90 0:170.91 74.54 4.64							
VRCS	0.413	0.055	0.039	2.423	201	113	88
Mnvr from Reboost: -176 86 -0.28:170.91 74.54 4.64							
VRCS	0.399	0.044	0.060	2.508	215	116	99
Mnvr from Reboost: 180 90 0:-9.09 105.46 -4.64							
VRCS	-0.077	0.066	0.039	12.932	2571	1093	1479
Mnvr from Reboost: -176 86 -0.28:-9.09 105.46 -4.64							
VRCS	-0.063	0.057	0.064	15.831	3027	1279	1748

Table 39: Estimated ΔV for maneuvers to and from deboost for Intermediate1 RRR

Attitude	ΔV_x	ΔV_y	ΔV_z	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
	(ft/sec)	(ft/sec)	(ft/sec)		Total	Fwd	Aft
Mnvr to Deboost: 170.99 73.55 4.80:-9.01 106.45 -4.80							
VRCS	-0.086	-0.011	0.163	11.577	2297	936	1361
Mnvr to Deboost: 170.99 73.55 4.80:0 90 0							
VRCS	-0.223	-0.088	0.017	4.484	841	403	438
Mnvr to Deboost: 170.99 73.55 4.80:3 94 0.21							
VRCS	-0.188	-0.085	0.050	5.306	978	449	530
Mnvr to Deboost: -9.01 106.45 -4.80:0 90 0							
VRCS	-0.744	-0.071	0.015	1.345	177	126	51
Mnvr to Deboost: -9.01 106.45 -4.80:3 94 0.21							
VRCS	-0.609	-0.028	0.055	1.642	190	125	65
Mnvr from Deboost: -9.01 106.45 -4.80:170.99 73.55 4.80							
VRCS	0.073	0.016	0.219	13.646	7617	5228	2388
Mnvr from Deboost: 0 90 0:170.99 73.55 4.80							
VRCS	-0.006	0.033	0.105	165.536	31414	21906	9507
Mnvr from Deboost: 3 94 0.21:170.99 73.55 4.80							
VRCS	-0.013	0.047	0.130	74.283	21269	14896	6372
Mnvr from Deboost: 0 90 0:-9.01 106.45 -4.80							
VRCS	-0.404	-0.081	0.050	2.477	197	112	86
Mnvr from Deboost: 3 94 0.21:-9.01 106.45 -4.80							
VRCS	-0.410	-0.080	0.078	2.436	210	116	95

Table 40: Estimated ΔV for maneuvers to and from deboost for Final RRR

Attitude	ΔV_x	ΔV_y	ΔV_z	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
	(ft/sec)	(ft/sec)	(ft/sec)		Total	Fwd	Aft
Mnvr to Deboost: 170.91 74.54 4.64:-9.09 105.46 -4.64							
VRCS	-0.101	-0.028	0.150	9.900	1863	763	1100
Mnvr to Deboost: 170.91 74.54 4.64:0 90 0							
VRCS	-0.234	-0.084	0.007	4.273	822	395	427
Mnvr to Deboost: 170.91 74.54 4.64:3 94 0.21							
VRCS	-0.219	-0.077	0.043	4.569	864	405	458
Mnvr to Deboost: -9.09 105.46 -4.64:0 90 0							
VRCS	-0.750	-0.069	0.015	1.333	178	125	53
Mnvr to Deboost: -9.09 105.46 -4.64:3 94 0.21							
VRCS	-0.622	-0.025	0.056	1.609	191	124	67
Mnvr from Deboost: -9.09 105.46 -4.64:170.91 74.54 4.64							
VRCS	0.094	0.012	0.218	10.673	27392	19106	8286
Mnvr from Deboost: 0 90 0:170.91 74.54 4.64							
VRCS	0.006	0.033	0.101	159.109	20040	13981	6058
Mnvr from Deboost: 3 94 0.21:170.91 74.54 4.64							
VRCS	-0.005	0.048	0.126	203.128	208273	143035	65238
Mnvr from Deboost: 0 90 0:-9.09 105.46 -4.64							
VRCS	-0.398	-0.078	0.049	2.513	201	114	87
Mnvr from Deboost: 3 94 0.21:-9.09 105.46 -4.64							
VRCS	-0.429	-0.084	0.080	2.330	214	117	97

Table 41: Estimated propellant usage for maneuvers to and from reboost attitudes for Intermediate1 RRR

Attitude	Total (lbs)	1 σ (lbs)	Aft (lbs)	1 σ (lbs)	Fwd (lbs)	1 σ (lbs)
Mnvr to Reboost: -9.01 106.45 -4.80:170.99 73.55 4.80						
VRCS	147.87	8.48	46.74	3.65	101.12	5.19
Mnvr to Reboost: 170.99 73.55 4.80:180 90 0						
VRCS	87.46	7.03	31.70	2.32	55.76	5.13
Mnvr to Reboost: 170.99 73.55 4.80:-176 86 -0.28						
VRCS	76.79	7.33	32.30	2.42	44.50	5.32
Mnvr to Reboost: -9.01 106.45 -4.80:180 90 0						
VRCS	152.98	9.40	47.47	3.99	105.51	5.79
Mnvr to Reboost: -9.01 106.45 -4.80:-176 86 -0.28						
VRCS	145.68	9.92	44.99	4.51	100.69	5.60
Mnvr from Reboost: 170.99 73.55 4.80:-9.01 106.45 -4.80						
VRCS	168.74	8.33	100.90	3.76	67.84	5.06
Mnvr from Reboost: 180 90 0:170.99 73.55 4.80						
VRCS	67.91	3.97	28.29	2.28	39.62	2.42
Mnvr from Reboost: -176 86 -0.28:170.99 73.55 4.80						
VRCS	71.19	2.70	32.75	1.76	38.43	2.01
Mnvr from Reboost: 180 90 0:-9.01 106.45 -4.80						
VRCS	165.11	5.38	95.64	3.04	69.47	2.84
Mnvr from Reboost: -176 86 -0.28:-9.01 106.45 -4.80						
VRCS	165.03	5.72	95.83	3.07	69.20	2.97

Table 42: Estimated propellant usage for maneuvers to and from reboost attitudes for Final RRR

Attitude	Total (lbs)	1 σ (lbs)	Aft (lbs)	1 σ (lbs)	Fwd (lbs)	1 σ (lbs)
Mnvr to Reboost: -9.09 105.46 -4.64:170.91 74.54 4.64						
VRCS	157.85	10.10	50.21	4.06	107.63	6.47
Mnvr to Reboost: 170.91 74.54 4.64:180 90 0						
VRCS	88.81	5.54	33.38	2.07	55.44	4.02
Mnvr to Reboost: 170.91 74.54 4.64:-176 86 -0.28						
VRCS	72.23	7.04	31.47	2.60	40.76	4.73
Mnvr to Reboost: -9.09 105.46 -4.64:180 90 0						
VRCS	159.01	10.13	49.57	3.65	109.44	7.16
Mnvr to Reboost: -9.09 105.46 -4.64:-176 86 -0.28						
VRCS	152.15	9.70	47.16	3.75	104.99	6.46
Mnvr from Reboost: 170.91 74.54 4.64:-9.09 105.46 -4.64						
VRCS	172.86	8.07	103.18	3.71	69.68	4.73
Mnvr from Reboost: 180 90 0:170.91 74.54 4.64						
VRCS	67.72	3.32	29.10	2.10	38.62	2.32
Mnvr from Reboost: -176 86 -0.28:170.91 74.54 4.64						
VRCS	69.86	3.08	32.55	1.87	37.32	2.21
Mnvr from Reboost: 180 90 0:-9.09 105.46 -4.64						
VRCS	167.84	6.95	96.84	3.88	71.00	3.43
Mnvr from Reboost: -176 86 -0.28:-9.09 105.46 -4.64						
VRCS	167.46	7.70	97.13	4.23	70.33	3.72

Table 43: Estimated propellant usage for maneuvers to and from deboost attitudes for Intermediate1 RRR

Attitude	Total (lbs)	1 σ (lbs)	Aft (lbs)	1 σ (lbs)	Fwd (lbs)	1 σ (lbs)
Mnvr to Deboost: 170.99 73.55 4.80:-9.01 106.45 -4.80						
VRCS	168.74	8.33	100.90	3.76	67.84	5.06
Mnvr to Deboost: 170.99 73.55 4.80:0 90 0						
VRCS	162.80	10.04	93.42	2.73	69.39	8.18
Mnvr to Deboost: 170.99 73.55 4.80:3 94 0.21						
VRCS	162.59	8.52	92.12	2.96	70.47	6.19
Mnvr to Deboost: -9.01 106.45 -4.80:0 90 0						
VRCS	93.97	4.62	35.43	1.87	58.54	3.59
Mnvr to Deboost: -9.01 106.45 -4.80:3 94 0.21						
VRCS	88.11	3.67	37.18	1.78	50.93	2.53
Mnvr from Deboost: -9.01 106.45 -4.80:170.99 73.55 4.80						
VRCS	147.87	8.48	46.74	3.65	101.12	5.19
Mnvr from Deboost: 0 90 0:170.99 73.55 4.80						
VRCS	142.41	4.35	42.61	2.14	99.81	2.60
Mnvr from Deboost: 3 94 0.21:170.99 73.55 4.80						
VRCS	135.68	3.84	41.05	2.03	94.63	2.26
Mnvr from Deboost: 0 90 0:-9.01 106.45 -4.80						
VRCS	67.77	2.49	29.37	2.01	38.40	1.45
Mnvr from Deboost: 3 94 0.21:-9.01 106.45 -4.80						
VRCS	73.04	2.49	34.22	1.88	38.82	1.70

Table 44: Estimated propellant usage for maneuvers to and from deboost attitudes for Final RRR

Attitude	Total (lbs)	1 σ (lbs)	Aft (lbs)	1 σ (lbs)	Fwd (lbs)	1 σ (lbs)
Mnvr to Deboost: 170.91 74.54 4.64:-9.09 105.46 -4.64						
VRCS	172.86	8.07	103.18	3.71	69.68	4.73
Mnvr to Deboost: 170.91 74.54 4.64:0 90 0						
VRCS	168.50	9.88	95.34	2.65	73.16	8.19
Mnvr to Deboost: 170.91 74.54 4.64:3 94 0.21						
VRCS	170.83	7.68	95.15	2.76	75.69	5.82
Mnvr to Deboost: -9.09 105.46 -4.64:0 90 0						
VRCS	95.98	4.65	37.13	1.92	58.85	3.52
Mnvr to Deboost: -9.09 105.46 -4.64:3 94 0.21						
VRCS	88.32	3.61	38.87	1.72	49.45	2.46
Mnvr from Deboost: -9.09 105.46 -4.64:170.91 74.54 4.64						
VRCS	157.85	10.10	50.21	4.06	107.63	6.47
Mnvr from Deboost: 0 90 0:170.91 74.54 4.64						
VRCS	145.64	4.70	43.92	2.38	101.72	2.73
Mnvr from Deboost: 3 94 0.21:170.91 74.54 4.64						
VRCS	139.58	6.07	42.75	2.70	96.83	3.71
Mnvr from Deboost: 0 90 0:-9.09 105.46 -4.64						
VRCS	65.81	4.00	29.54	3.08	36.27	1.49
Mnvr from Deboost: 3 94 0.21:-9.09 105.46 -4.64						
VRCS	73.83	2.87	35.63	2.10	38.20	1.84

6 STS-128/17A Maneuver Performance

STS-128/17A has been certified with VRCS for rotational maneuvers with a maneuver rate of $0.10^\circ/\text{sec}$. However, due to likelihood of poor performance, ALT LowZ±X NFY is not certified for maneuvers and is to be used only if no other control modes are available. The results for ALT maneuvers presented in this document are for reference only. Due to loads constraints, all ALT maneuvers for STS-128/17A mated configurations must be 1-jet with a 7.04 sec delay.

VRCS provides acceptable control for attitude maneuvers. However, as with recent ISS assembly flights, VRCS maneuvers may exhibit some non-ideal behavior during mated flight. One phenomenon observed with VRCS control in pre-flight analysis is toggling of the thrusters during certain rotational maneuvers. When such jet toggling occurs, one or more jets will cycle on and off anywhere from 10 to 60 times over the course of 120 seconds as the desired rate is approached. Toggling such as this is usually mild and not an issue. There is little that can be done about such toggling with the current flight software. Should this toggling become an issue on a future flight, then the only alternative is to reduce the VRCS maneuver rate, as was done with the ALT maneuver rate.

A second phenomenon observed with both VRCS and ALT control is maneuver chasing. For some rotation maneuvers, control authority can be somewhat marginal as compared to the maneuver rate. As the end of the maneuver approaches, the DAP is unable to change the rotational rate fast enough in order for the maneuver to converge upon the desired attitude properly. The commanded rates are changing too rapidly for the jets to be able to respond in time. The end result is that the attitude and rate errors may “orbit” the phase plane until the DAP is able to bring the maneuver to an end, resulting in longer maneuver times and more propellant usage than would otherwise be required. Maneuver chasing was observed in simulation occasionally for VRCS control and for a significant number of cases for ALT control.

6.1 Generic Maneuvers

Both generic maneuvers and mission specific maneuvers have been analyzed for STS-128/17A. The generic maneuvers analyzed were random LVLH maneuvers from one random LVLH attitude to a second random LVLH attitude.

For both the Intermediate1 and Final models, 10,000 generic maneuvers were run with VRCS as well as 1-jet ALT with 7.04 second delay. Initial rate errors up to $\pm 0.01^\circ/\text{sec}$ were applied per axis. A uniform distribution of modal uncertainties was applied to the flex model ($\pm 20\%$ frequency and $\pm 4\text{dB}$ amplitude). Results for the the RRR configuration with and without HTV1 are shown.

6.1.1 RRR

For the RRR configuration, a plot of maneuver time versus eigen-angle for the Intermediate1 STS-128/17A configuration is shown in Figure 9. The scatter plots are the results of the 10,000 random maneuvers for both ALT and VRCS. For most maneuvers, the maneuver time is close to the eigen-angle divided by the maneuver rate, producing the two bands of points in the plot. Many more ALT maneuvers exhibit maneuver chasing than with VRCS, and thus take longer than the expected time. In fact, there were 28 cases with ALT in which the target attitude was not reached by the end of the simulation (5400 sec). These failed maneuvers, artificially plotted at 6000 seconds in Figure 9, are typically large-angle maneuvers and can usually be completed if given enough time. For the maneuvers that completed in 5400 seconds with ALT, Figures 10 and 11 show the additional time needed to complete the maneuver beyond the expected time.

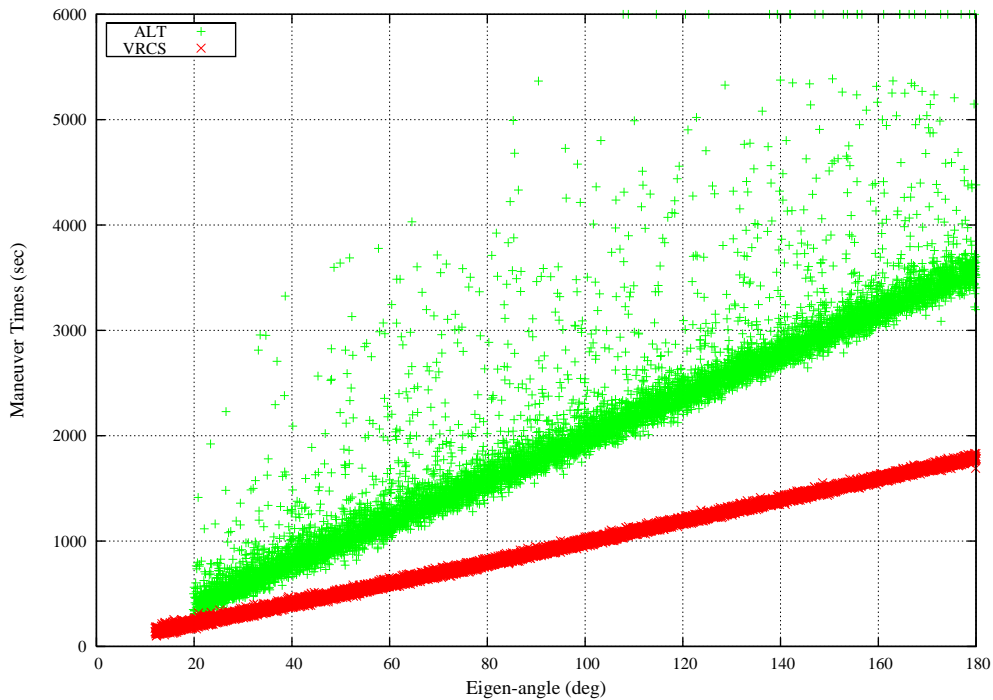


Figure 9: Maneuver Time versus Eigen-angle for STS-128/17A Intermediate1, RRR

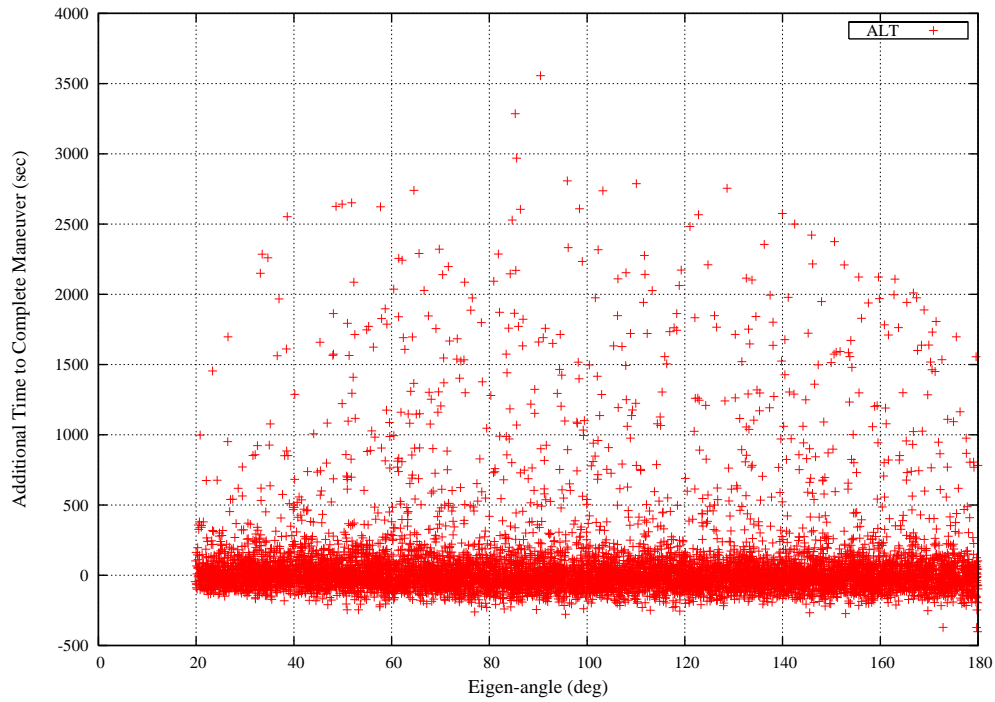


Figure 10: Additional Time to Complete Maneuver versus Eigen-angle for STS-128/17A Intermediate1, RRR

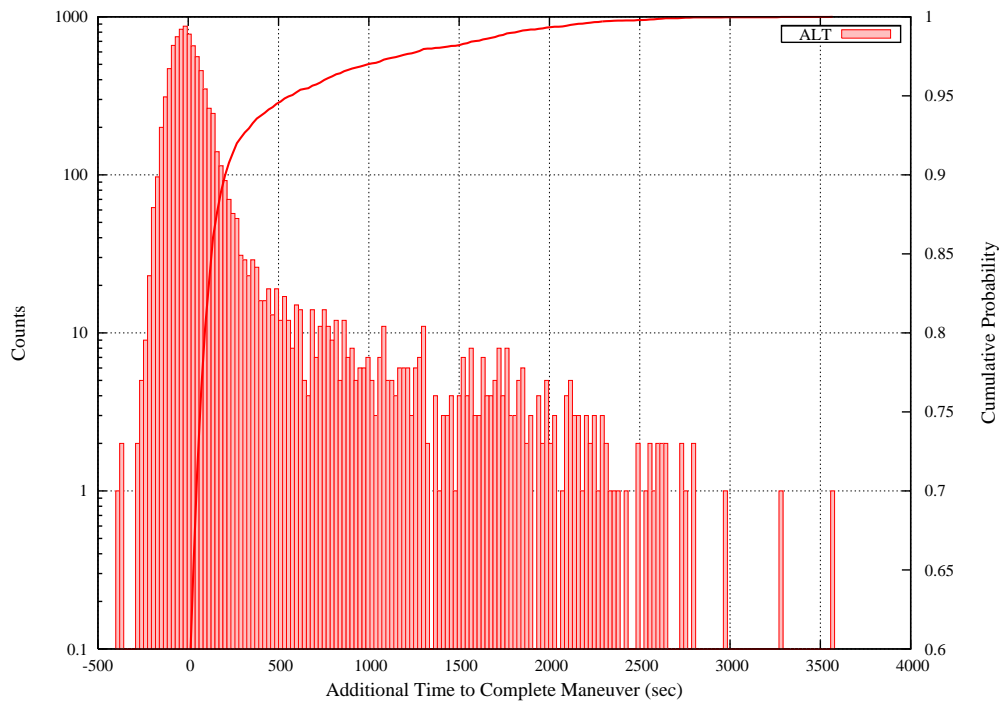


Figure 11: Histogram of Additional Time to Complete Maneuver for STS-128/17A Intermediate1, RRR

A plot of the total propellant versus eigen-angle is shown in Figure 12. The linear fits for VRCS and ALT are plotted as dashed lines. As can be seen in the plots, ALT is generally more propellant efficient than VRCS for maneuvers. This difference is primarily due to the reduced maneuver rate for ALT.

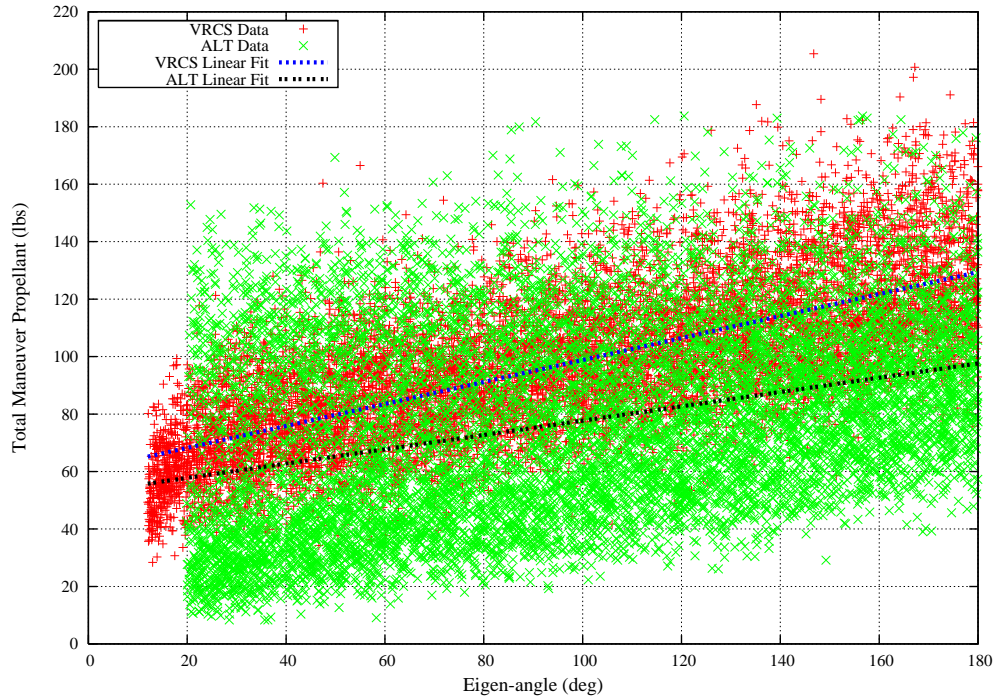


Figure 12: Total Maneuver Propellant versus Eigen-angle for STS-128/17A Intermediate1, RRR

For generic VRCS maneuvers of a given eigen-angle, θ , given in degrees, the propellant usage for the Intermediate1 configuration can be approximated via the following:

$$\text{Total VRCS Propellant (lbs)} = 0.38 \cdot \theta + 61 \text{ lbs}; \quad 1\sigma = \pm 19 \text{ lbs} \quad (2)$$

$$\text{Aft VRCS Propellant (lbs)} = 0.18 \cdot \theta + 28 \text{ lbs}; \quad 1\sigma = \pm 12 \text{ lbs} \quad (3)$$

$$\text{Fwd VRCS Propellant (lbs)} = 0.20 \cdot \theta + 33 \text{ lbs}; \quad 1\sigma = \pm 13 \text{ lbs} \quad (4)$$

Likewise, for generic ALT maneuvers, the propellant usage for the Intermediate1 configuration can be approximated by the following:

$$\text{Total ALT Propellant (lbs)} = 0.25 \cdot \theta + 53 \text{ lbs}; \quad 1\sigma = \pm 32 \text{ lbs} \quad (5)$$

$$\text{Aft ALT Propellant (lbs)} = 0.12 \cdot \theta + 25 \text{ lbs}; \quad 1\sigma = \pm 15 \text{ lbs} \quad (7)$$

$$\text{Fwd ALT Propellant (lbs)} = 0.13 \cdot \theta + 28 \text{ lbs}; \quad 1\sigma = \pm 21 \text{ lbs} \quad (8)$$

For the Final STS-128/17A configuration, a plot of maneuver time versus eigen-angle is shown in Figure 13. The plot shows significantly more ALT maneuvers taking longer to complete. There are also many failed maneuvers. Table 45 shows the number of cases out of the 10,000 runs that exhibited maneuver chasing or failed. Figure 14 shows a typical failed maneuver.

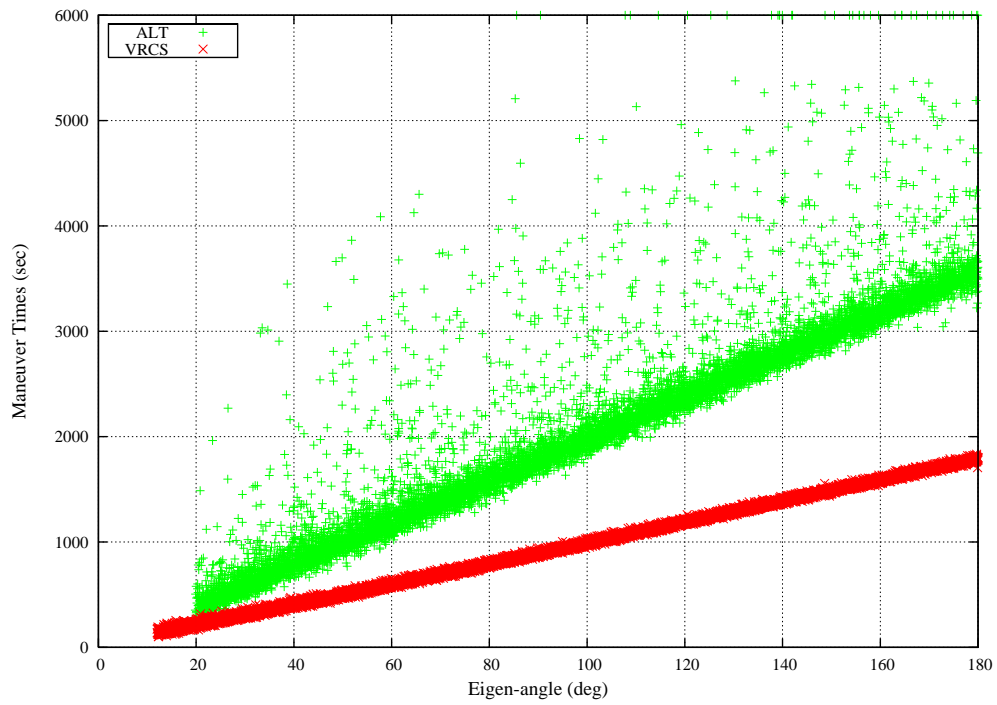


Figure 13: Maneuver Time versus Eigen-angle for STS-128/17A Final, RRR

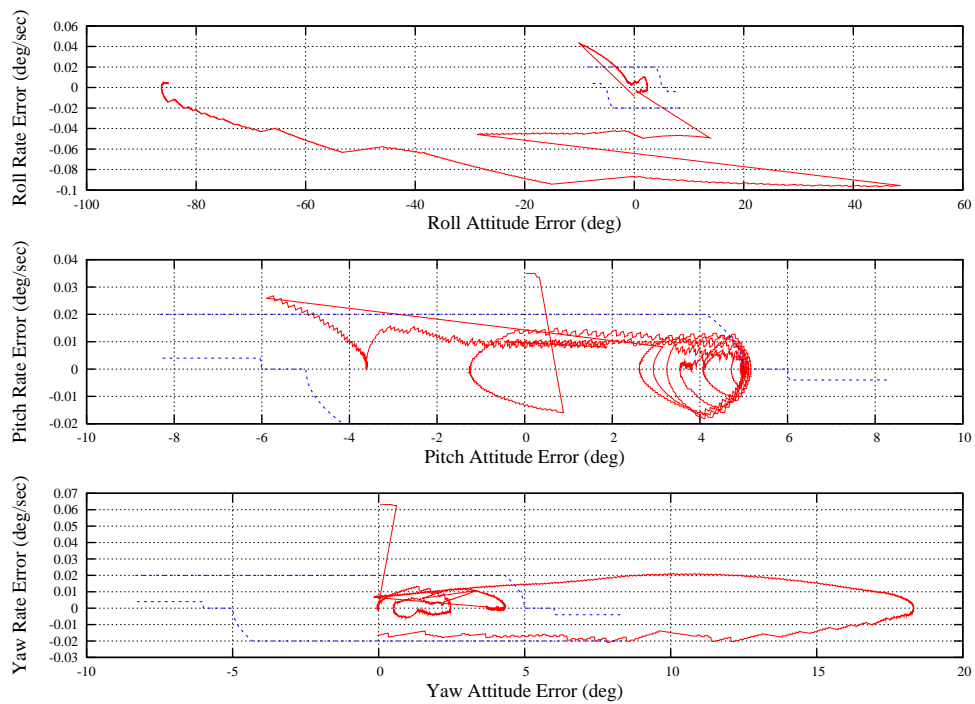


Figure 14: Phase planes for failed ALT maneuver for STS-128/17A Final, RRR

Table 45: STS-128 ALT Maneuver Chasing and Failed Maneuvers

Configuration	Visiting Vehicles	# of Cases with Maneuver Chasing out of 10,000 runs	# of Failed Maneuvers out of 10,000 runs
Intermediate1	RRR	138	28
Final	RRR	151	39

The total propellant versus eigen-angle for the Final STS-128/17A configuration is plotted in Figure 15. In the Final configuration, the VRCS propellant usage can be approximated via the following:

$$\text{Total VRCS Propellant (lbs)} = 0.39 \cdot \theta + 62 \text{ lbs}; \quad 1\sigma = \pm 19 \text{ lbs} \quad (9)$$

$$\text{Aft VRCS Propellant (lbs)} = 0.18 \cdot \theta + 29 \text{ lbs}; \quad 1\sigma = \pm 13 \text{ lbs} \quad (10)$$

$$\text{Fwd VRCS Propellant (lbs)} = 0.20 \cdot \theta + 33 \text{ lbs}; \quad 1\sigma = \pm 14 \text{ lbs} \quad (11)$$

Similarly, the ALT propellant usage for the Final configuration can be approximated by the following:

$$\text{Total ALT Propellant (lbs)} = 0.26 \cdot \theta + 53 \text{ lbs}; \quad 1\sigma = \pm 32 \text{ lbs} \quad (12)$$

$$\text{Aft ALT Propellant (lbs)} = 0.12 \cdot \theta + 25 \text{ lbs}; \quad 1\sigma = \pm 15 \text{ lbs} \quad (13)$$

$$\text{Fwd ALT Propellant (lbs)} = 0.14 \cdot \theta + 28 \text{ lbs}; \quad 1\sigma = \pm 21 \text{ lbs} \quad (14)$$

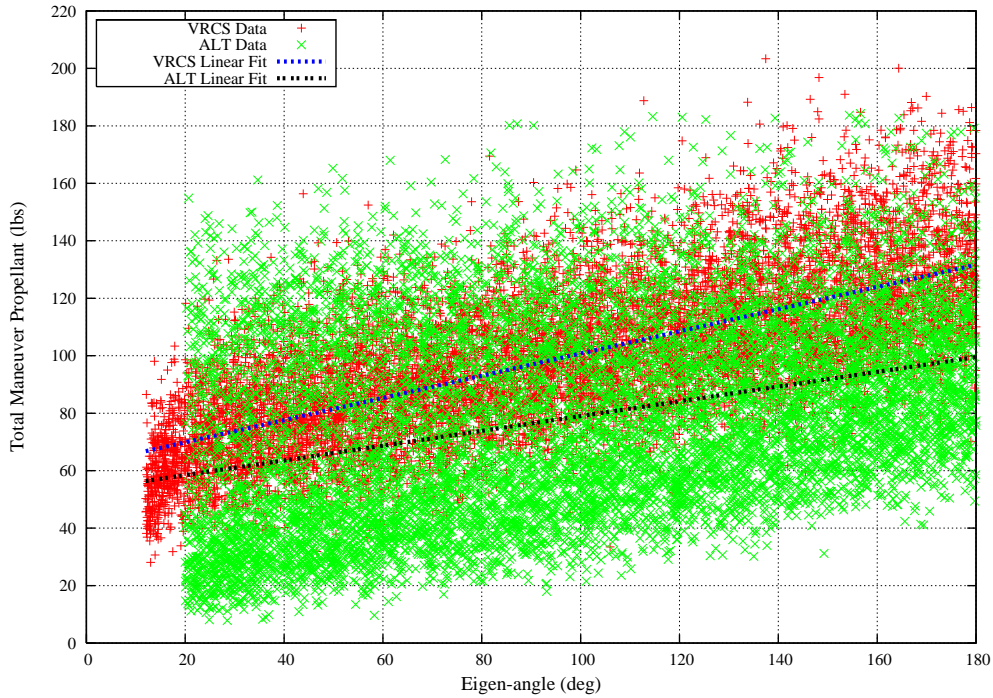


Figure 15: Total Maneuver Propellant versus Eigen-angle for STS-128/17A Final, RRR

6.1.2 RRR with HTV

For the RRR HTV configuration, a plot of the total propellant versus eigen-angle for the Intermediate1 STS-128/17A configuration is shown in Figure 16. The scatter plots are the results of the 10,000 random VRCS maneuvers. The linear fit is plotted as a dashed line. ALT generic maneuvers were not simulated for this case.

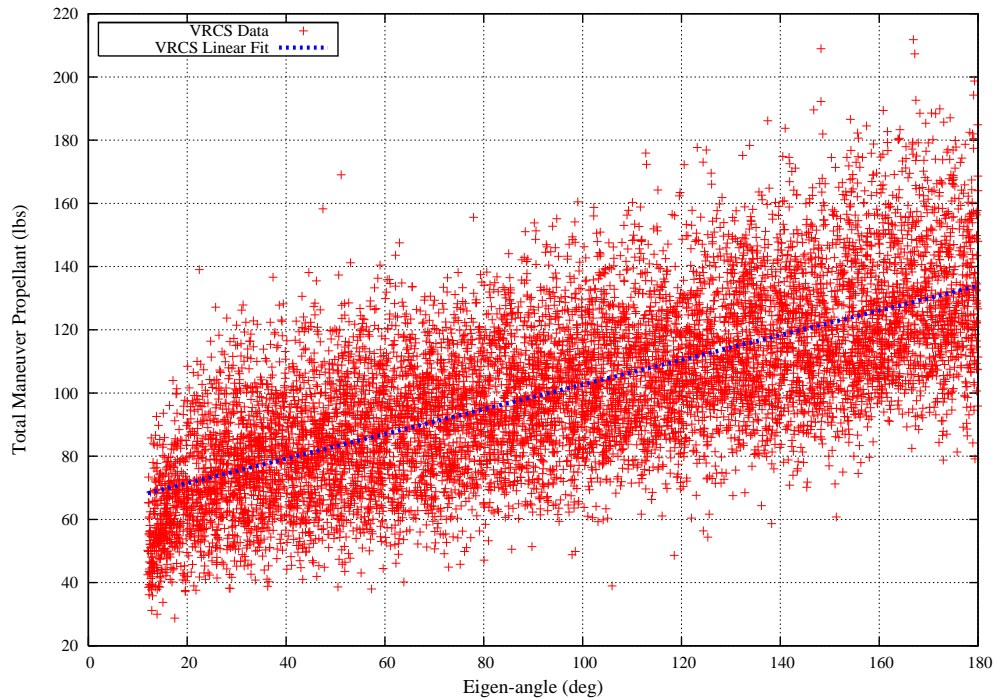


Figure 16: Total Maneuver Propellant versus Eigen-angle for STS-128/17A Intermediate1, RRR HTV

For generic VRCS maneuvers of a given eigen-angle, θ , given in degrees, the propellant usage for the Intermediate1 configuration for RRR HTV can be approximated via the following:

$$\text{Total VRCS Propellant (lbs)} = 0.39 \cdot \theta + 64 \text{ lbs}; \quad 1\sigma = \pm 20 \text{ lbs} \quad (15)$$

$$\text{Aft VRCS Propellant (lbs)} = 0.18 \cdot \theta + 28 \text{ lbs}; \quad 1\sigma = \pm 12 \text{ lbs} \quad (16)$$

$$\text{Fwd VRCS Propellant (lbs)} = 0.21 \cdot \theta + 35 \text{ lbs}; \quad 1\sigma = \pm 14 \text{ lbs} \quad (17)$$

The total propellant versus eigen-angle for the Final STS-128/17A configuration for RRR HTV is plotted in Figure 17. In the Final configuration, the VRCS propellant usage can be approximated via the following:

$$\text{Total VRCS Propellant (lbs)} = 0.40 \cdot \theta + 65 \text{ lbs}; \quad 1\sigma = \pm 20 \text{ lbs} \quad (18)$$

$$\text{Aft VRCS Propellant (lbs)} = 0.18 \cdot \theta + 29 \text{ lbs}; \quad 1\sigma = \pm 13 \text{ lbs} \quad (19)$$

$$\text{Fwd VRCS Propellant (lbs)} = 0.21 \cdot \theta + 36 \text{ lbs}; \quad 1\sigma = \pm 14 \text{ lbs} \quad (20)$$

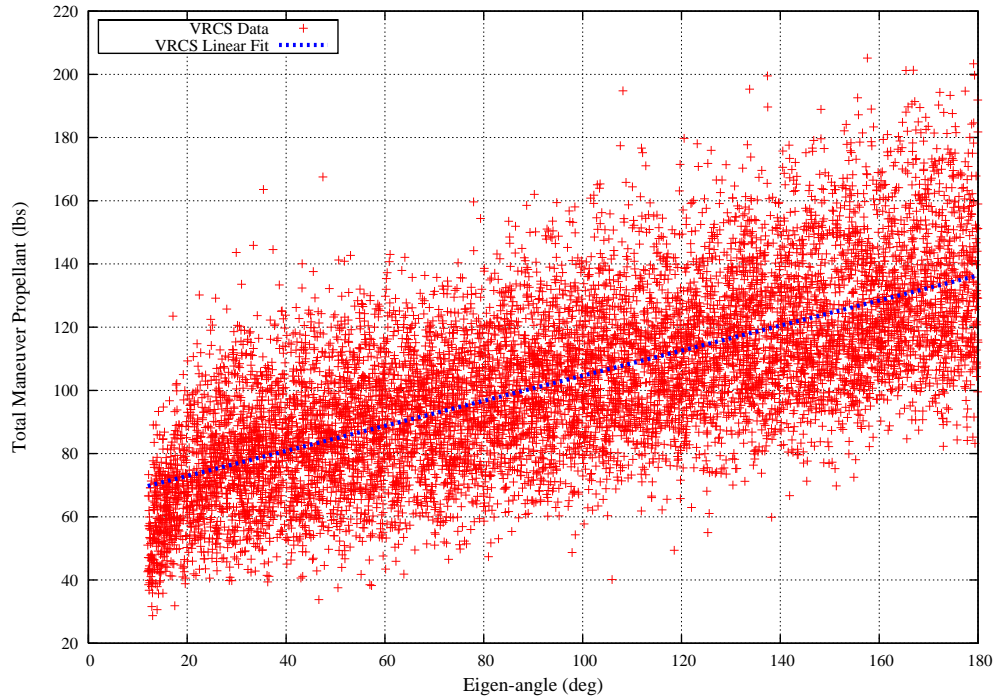


Figure 17: Total Maneuver Propellant versus Eigen-angle for STS-128/17A Final, RRR HTV

6.1.3 Jet Firing Statistics

Tables 46 and 47 summarize the observed jet firing statistics from the Monte Carlo maneuver cases for VRCS and ALT respectively. Both tables contain the combined results of both the Intermediate1 and Final configurations. For the vernier results, the Max-On columns show the on-times statistics of any *single continuous* vernier jet firing. As seen in the table, the maximum continuous on-time for any jet does not exceed the 500 second SODB limit for the configurations shown (for the RxR HTV configuration, there was one case which violated this limit). The Firings column shows that the SODB limit of no more than 1,000 firings in an hour is met for all of the maneuvers. The last columns of data contain the statistics for the total on-time of the given jet over the course of the maneuver. Since ALT limits the on-times to 80ms and there are no constraints on the number of ALT pulses, only the total on-time data is shown in Table 47.

Table 46: STS-128/17A VRCS Firing Statistics for Generic Maneuvers

Jet ID	Max-On (sec)		Firings			Total On-time (sec)		
	Avg.	Max.	Avg.	Max.	1 σ	Avg.	Max.	1 σ
RRR								
F5L	142.64	340.00	26	182	23	356.56	975.36	167.52
F5R	161.04	402.00	21	164	19	399.44	1009.36	176.46
L5D	63.17	273.44	80	381	49	215.33	717.28	112.87
L5L	37.31	140.72	50	233	38	100.09	322.24	58.19
R5D	68.34	350.72	82	441	49	234.25	801.60	125.07
R5R	39.09	154.32	54	222	40	107.71	346.48	60.69
RRR HTV								
F5L	156.67	356.88	26	212	23	374.86	1043.44	170.72
F5R	176.28	397.60	21	163	19	419.16	1042.40	179.66
L5D	62.08	227.52	84	375	51	214.31	748.40	110.92
L5L	37.21	141.60	52	258	40	99.97	318.80	57.82
R5D	67.93	368.56	86	436	52	234.38	766.64	123.01
R5R	38.89	153.68	56	247	42	107.25	332.96	60.20

Table 47: STS-128/17A ALT Firing Statistics for Generic Maneuvers

Jet ID	Total On-time (sec)		
	Avg.	Max.	1 σ
RRR			
F1D	5.36	23.68	4.76
F2D	6.18	26.00	5.36
F3F	3.11	19.60	3.20
L1A	1.81	16.80	2.57
L1L	2.00	8.88	1.77
L2D	3.03	22.88	3.37
R1A	1.39	16.00	2.13
R1R	2.13	9.92	1.87
R2D	2.68	24.32	3.02

6.2 Mission Specific Maneuvers

All of the mission specific maneuvers as documented in the STS-128/17A Final ATL (July 22, 2009) have been simulated and examined for the RRR configuration (only this configuration was examined since the ATL attitudes are mass property dependent). For each of the maneuvers in the ATL, 100 cases with dispersed mass properties ($\pm 1\%$ in inertia, ± 6 inches in center of mass), initial rate errors ($\pm 0.01^\circ/\text{sec}$), and modal uncertainties ($\pm 4\text{dB}$ amplitude, $\pm 20\%$ frequency) were run. The results are summarized in Table 48. The maneuver number in the table corresponds to the number given in the ATL for the target attitude. The table shows the Orbiter body attitudes relative to LVLH which are expressed by a PYR Euler angle sequence given in RPY order. Some maneuvers were too small to trip the auto-maneuver logic and thus no true maneuver occurred. The estimated propellant in those cases was the total from the run. The amount of reboost or deboost obtained from performing the maneuvers is given in Table 49. The average ΔV values shown were taken from the end of the simulations (at 3600 sec for VRCS and 5400 sec for ALT).

The post-docking maneuver was also simulated for 10,000 cases with modal uncertainties of $\pm 4\text{dB}$ amplitude and $\pm 20\%$ frequency. The simulations were initialized with random rate errors up to $\pm 0.01^\circ/\text{sec}$ in roll and yaw, and pitch errors ranging from -0.04 to $-0.01^\circ/\text{sec}$. Each run started with a random free-drift period of duration 800 to 2400 sec. Then the DAP was moded to LVLH for 300 seconds, followed by FREE and then AUTO to start the maneuver. The total propellant is plotted versus Orbiter pitch angle in Figure 18.

Table 48: Estimated propellant usage for selected ATL maneuvers for RRR

ATL Attitude	Total lbs	1σ lbs	Aft lbs	1σ lbs	Fwd lbs	1σ lbs
31: 170.99 73.55 4.80:168.10 73.82 5.64 – Mnvr to Water Dump Attitude						
ALT lzxnfy-1 ¹	23.80	4.22	13.59	4.40	10.20	3.14
VRCS ¹	18.75	4.19	8.11	2.13	10.64	2.68
32: 168.10 73.82 5.64:170.91 74.54 4.64 – Mnvr to –XVV Mated TEA						
ALT lzxnfy-1 ¹	23.27	4.56	14.78	4.84	8.49	2.74
VRCS ¹	18.70	4.58	7.58	1.88	11.13	3.25
33: 170.91 74.54 4.64:0.00 90.00 0.00 – Mnvr to Undock Attitude						
ALT lzxnfy-1	106.85	4.96	42.96	3.85	63.89	4.27
VRCS	166.13	11.07	95.31	2.67	70.82	9.24

¹ Did not break maneuver threshold

Table 49: Estimated ΔV for selected ATL maneuvers for RRR

ATL Attitude	ΔV_x (ft/sec)	ΔV_y (ft/sec)	ΔV_z (ft/sec)	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
					Total	Fwd	Aft
31: 170.99 73.55 4.80:168.10 73.82 5.64 – Mnvr to Water Dump Attitude							
ALT lzxnfy-1 ¹	0.035	0.004	0.006	43.403	1097	512	584
VRCS ¹	0.091	0.025	0.022	10.948	206	117	89
32: 168.10 73.82 5.64:170.91 74.54 4.64 – Mnvr to -XVV Mated TEA							
ALT lzxnfy-1 ¹	0.031	0.008	-0.009	48.454	1212	481	730
VRCS ¹	0.093	0.018	0.021	10.791	204	120	84
33: 170.91 74.54 4.64:0.00 90.00 0.00 – Mnvr to Undock Attitude							
ALT lzxnfy-1	-0.105	-0.056	0.068	14.311	1165	664	501
VRCS	-0.236	-0.084	0.007	4.242	812	388	424

¹ Did not break maneuver threshold

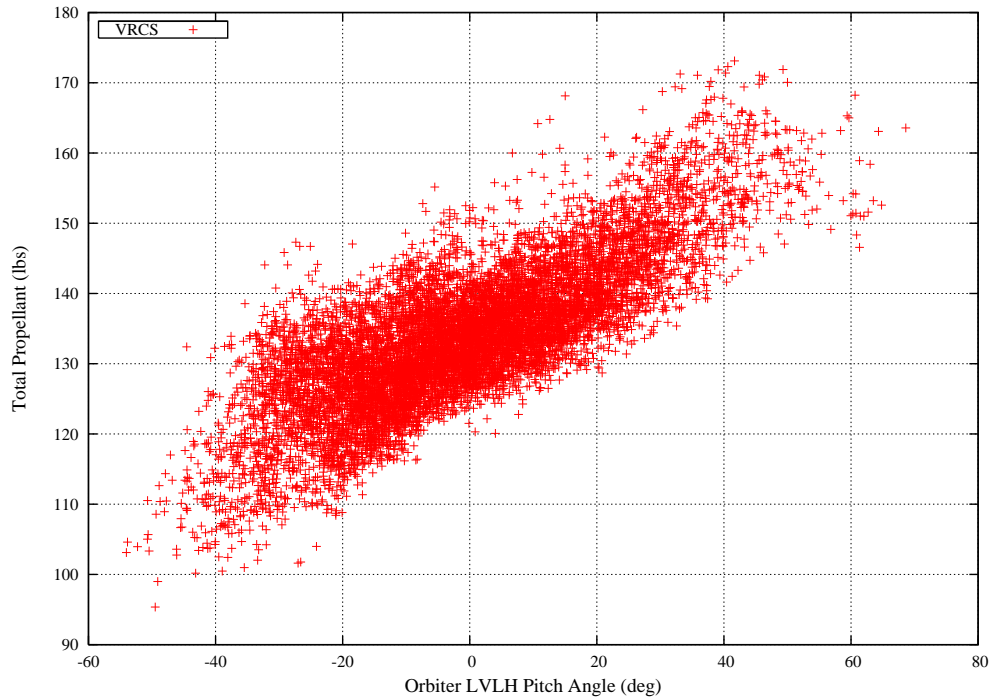


Figure 18: Post-docking Maneuver Propellant versus Orbiter Pitch Angle for STS-128/17A RRR

7 STS-128/17A Attitude Hold Performance

STS-128/17A has been certified with two jet control modes for attitude hold — VRCS and ALT LowZ±X NFY; the certified DAP settings are listed in Table 50. Single-jet ALT mode with 7.04 sec delay time is the only ALT configuration certified for this mission.

Table 50: STS-128 DAP settings for VRCS and 1-jet ALT attitude holds

Mode	DB deg	RL deg/s	MR deg/s
VRCS	1.0	0.02	0.01
ALT	1.0	0.02	0.01

As with previous flights, different attitude and rate deadbands are assigned for attitude holds and maneuvers for STS-128. There are two reasons to have separate deadbands for attitude holds and maneuvers. The first reason is that ISS has levied a tighter requirement on errors at undocking. The second reason is for reducing propellant usage while holding attitude at an unstable TEA. These two factors necessitate a reduction in attitude and rate deadbands in order to meet attitude control requirements.

The main reason for the VRCS attitude hold DAP is the undocking rate required by ISS [4]. With the increase in ISS mass, the ISS control system is challenged to maintain control in the face of the undocking disturbances. A requirement for rates no higher than $0.020^\circ/\text{sec}$ at undocking has been levied against the Orbiter DAP. For VRCS, the expedient solution is to drop the rate deadband to below the requirement. With a decrease in rate deadband, a concomitant decrease in attitude deadband is prudent to maintain good control. Thus the attitude hold DAP for VRCS is specifically designed to meet the ISS undocking requirement.

However, the VRCS attitude hold DAP has benefits beyond that of just undocking. First, the deadband reduction will reduce the rates that the ISS control system must deal with when handing over control from the Orbiter to the ISS. This will improve ISS control system convergence times and reduce stress on the ISS jets and CMGs. Second, since the ISS is no longer rotationally stable due to the truss build out, the reduced deadbands will significantly decrease propellant usage for the most part.

7.1 ISS Attitude Envelope

The usual suite of pitch attitudes from the nominal -XVV ISS assembly attitude envelope was run for STS-128/17A for the six visiting vehicle configurations (RRR, RRx, RxR, RRR HTV, RRx HTV, RxR HTV). For each pitch attitude between 0° and 30° , 10 cases with dispersed mass properties ($\pm 1\%$ in inertia, ± 6 inches in center of mass), initial rate errors ($\pm 0.01^\circ/\text{sec}$), and modal uncertainties ($\pm 4\text{dB}$ amplitude, $\pm 20\%$ frequency) were run. The yaw/roll offset in ISS is $y=180^\circ$ and $r=0^\circ$. The attitude hold DAP was used for all results unless otherwise stated. VRCS

attitude hold with the maneuver DAP (A12) was performed for RRR for comparison with the hold DAP (B12). Figures 19 through 25 show the propellant usages for VRCS and ALT across the 30° ISS pitch attitude envelope for the Intermediate1 and Final STS-128/17A configurations. Table 51 lists the largest attitude and rate errors during attitude hold with each DAP. The minimum, average, and maximum propellant usage over the envelope for each visiting vehicle configuration are shown in Table 52. For RRR, the propellant statistics per attitude shown in the plots are given for the attitude hold DAP in tabular form in Tables 53 through 56.

Table 51: Maximum attitude and rate errors for generic attitude holds for RRR

DAP	Jet Mode	Max Attitude Error (deg)			Max Rate Error (deg/sec)		
		Roll	Pitch	Yaw	Roll	Pitch	Yaw
B12	VRCS	1.04	1.05	1.01	0.0087	0.0120	0.0099
B12	ALT	1.29	1.21	1.16	0.0087	0.0123	0.0093
A12	VRCS	3.07	3.22	3.05	0.0109	0.0200	0.0125

Table 52: STS-128 Generic Attitude Hold Total Propellant Usage ($\gamma=180^\circ$, $\rho=0^\circ$)

Configuration	Visiting Vehicles	DAP	Jet Mode	Min lbs/hr	Avg lbs/hr	Max lbs/hr
Intermediate1	RRR	A12	VRCS	10.29	28.92	58.98
Final	RRR	A12	VRCS	9.87	28.12	56.81
Intermediate1	RRR	B12	VRCS	5.72	24.15	52.81
Intermediate1	RRR	B12	ALT	5.52	13.54	22.98
Final	RRR	B12	VRCS	6.32	24.50	53.03
Final	RRR	B12	ALT	5.43	13.67	22.98
Intermediate1	RRx	B12	VRCS	6.20	22.69	48.96
Intermediate1	RRx	B12	ALT	5.14	12.76	20.36
Final	RRx	B12	VRCS	6.06	23.51	49.72
Final	RRx	B12	ALT	5.52	12.97	21.40
Intermediate1	RxR	B12	VRCS	5.87	25.01	54.67
Intermediate1	RxR	B12	ALT	5.10	13.39	21.94
Final	RxR	B12	VRCS	5.54	25.42	57.76
Final	RxR	B12	ALT	5.52	13.77	23.06
Intermediate1	RRR HTV	B12	VRCS	6.59	23.46	51.60
Intermediate1	RRR HTV	B12	ALT	5.52	13.46	24.30
Final	RRR HTV	B12	VRCS	5.90	23.93	52.36
Final	RRR HTV	B12	ALT	5.39	13.50	22.56
Intermediate1	RRx HTV	B12	VRCS	5.36	21.80	47.99
Intermediate1	RRx HTV	B12	ALT	5.10	12.53	19.78
Final	RRx HTV	B12	VRCS	5.94	22.88	49.68
Final	RRx HTV	B12	ALT	5.68	12.92	20.94
Intermediate1	RxR HTV	B12	VRCS	6.22	24.17	54.45
Intermediate1	RxR HTV	B12	ALT	5.14	13.25	21.48
Final	RxR HTV	B12	VRCS	5.88	24.78	56.83
Final	RxR HTV	B12	ALT	5.06	13.47	22.31

17A RRR

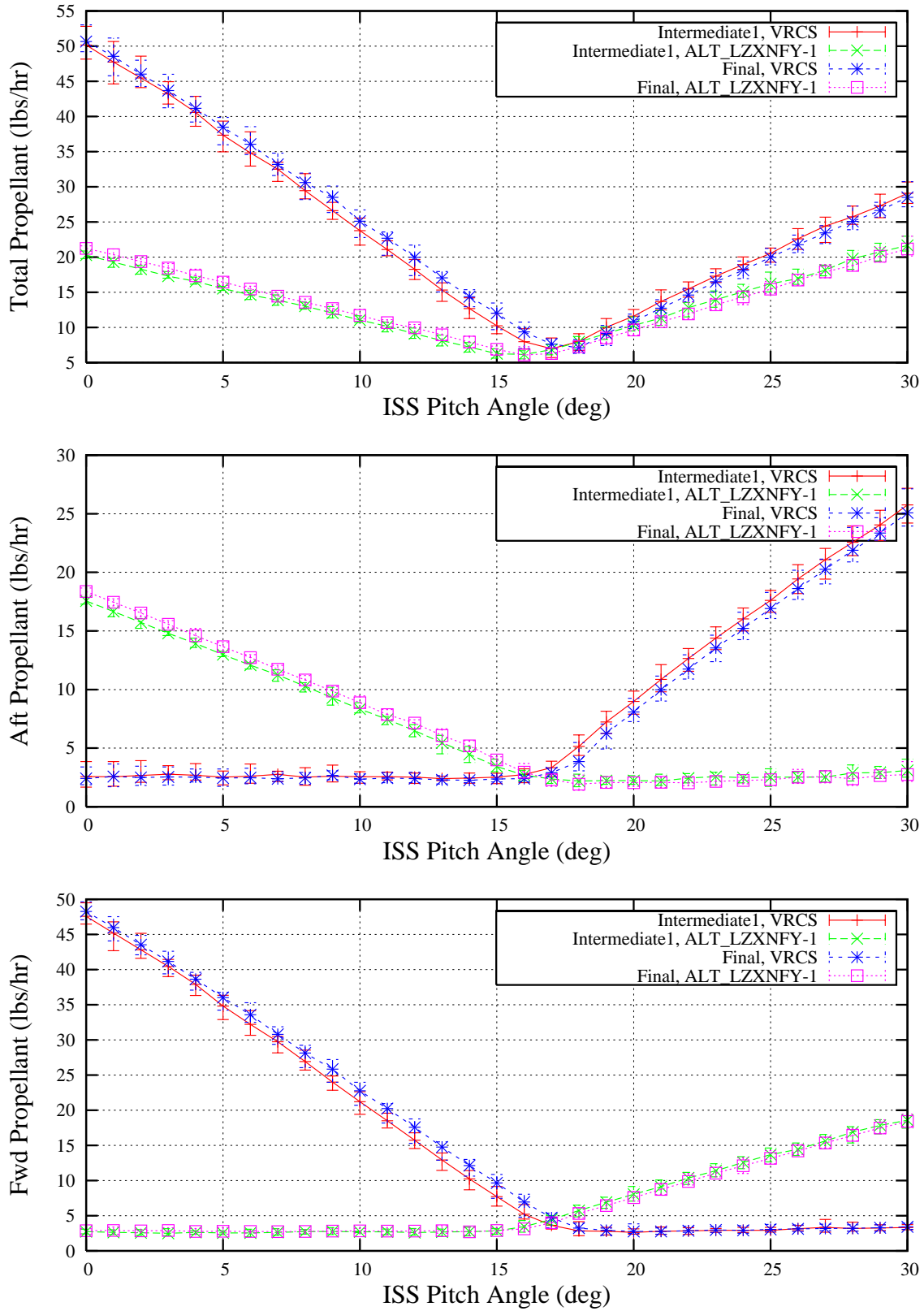


Figure 19: STS-128/17A Attitude Hold Propellant vs LVLH Pitch Angle, RRR ($y=180^\circ$, $r=0^\circ$)

17A RRR

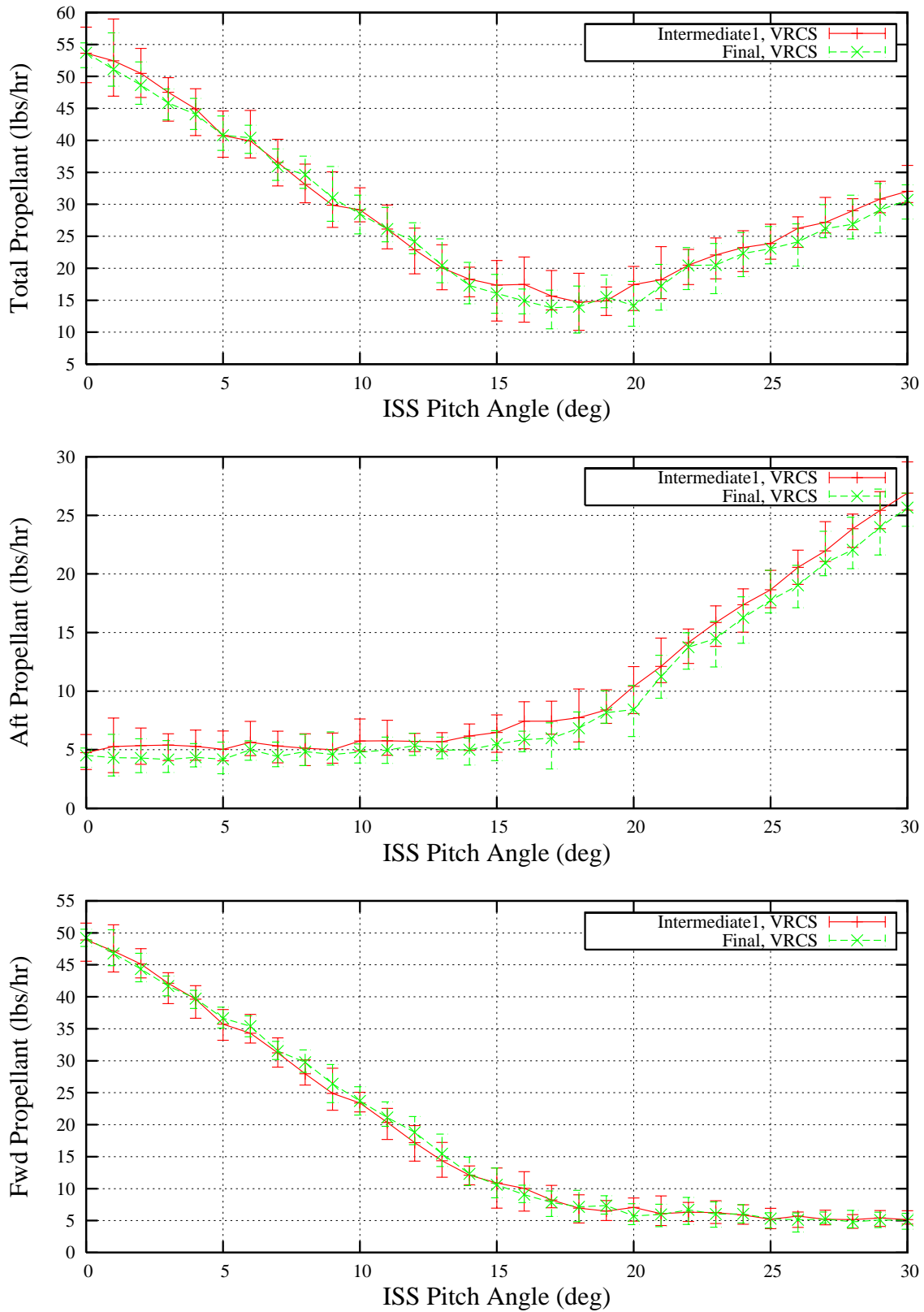


Figure 20: STS-128/17A Attitude Hold with *maneuver* DAP Propellant vs LVLH Pitch Angle, RRR ($y=180^\circ$, $r=0^\circ$)

17A RRx

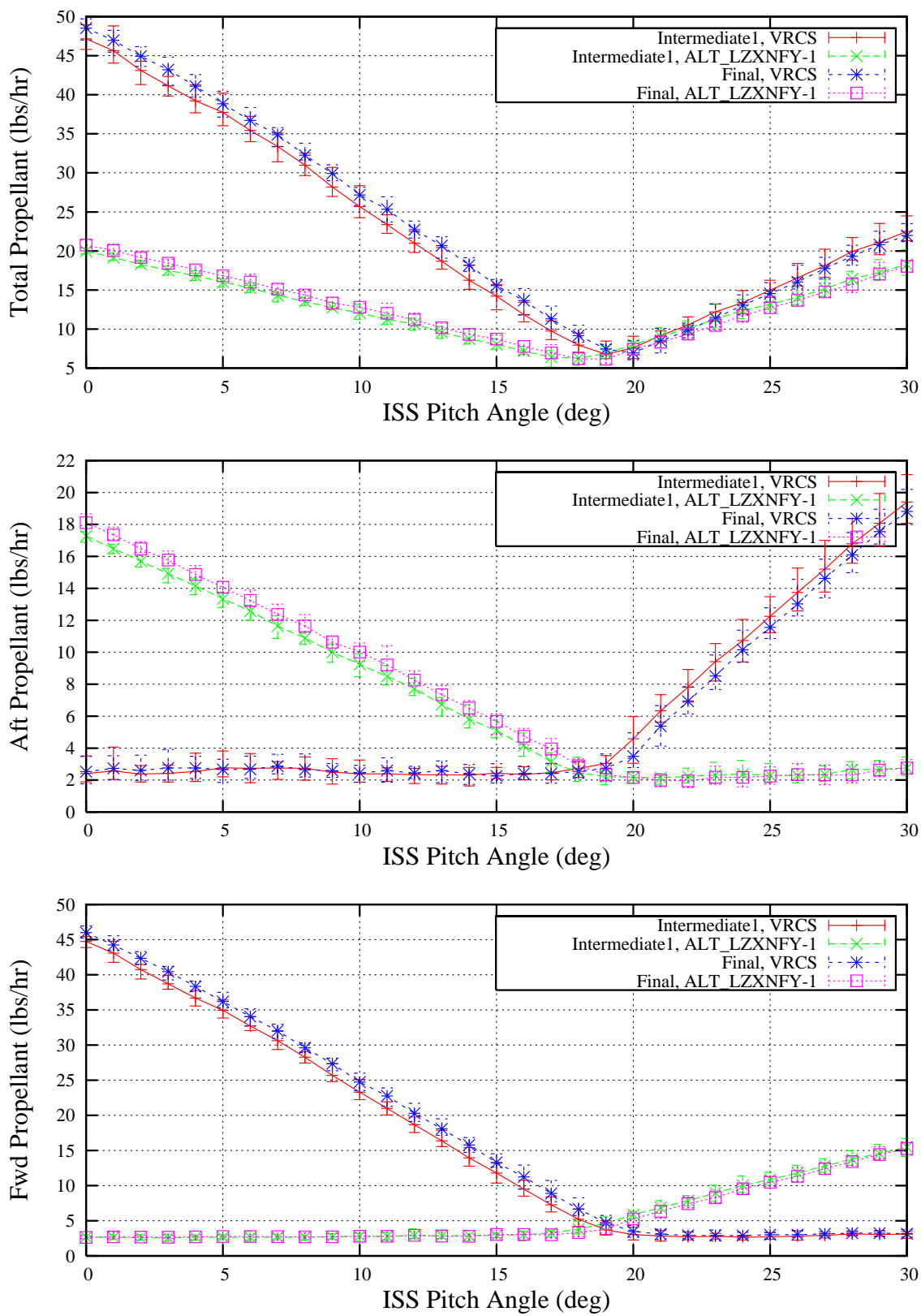


Figure 21: STS-128/17A Attitude Hold Propellant vs LVLH Pitch Angle, RRx ($y=180^\circ$, $r=0^\circ$)

17A RxR

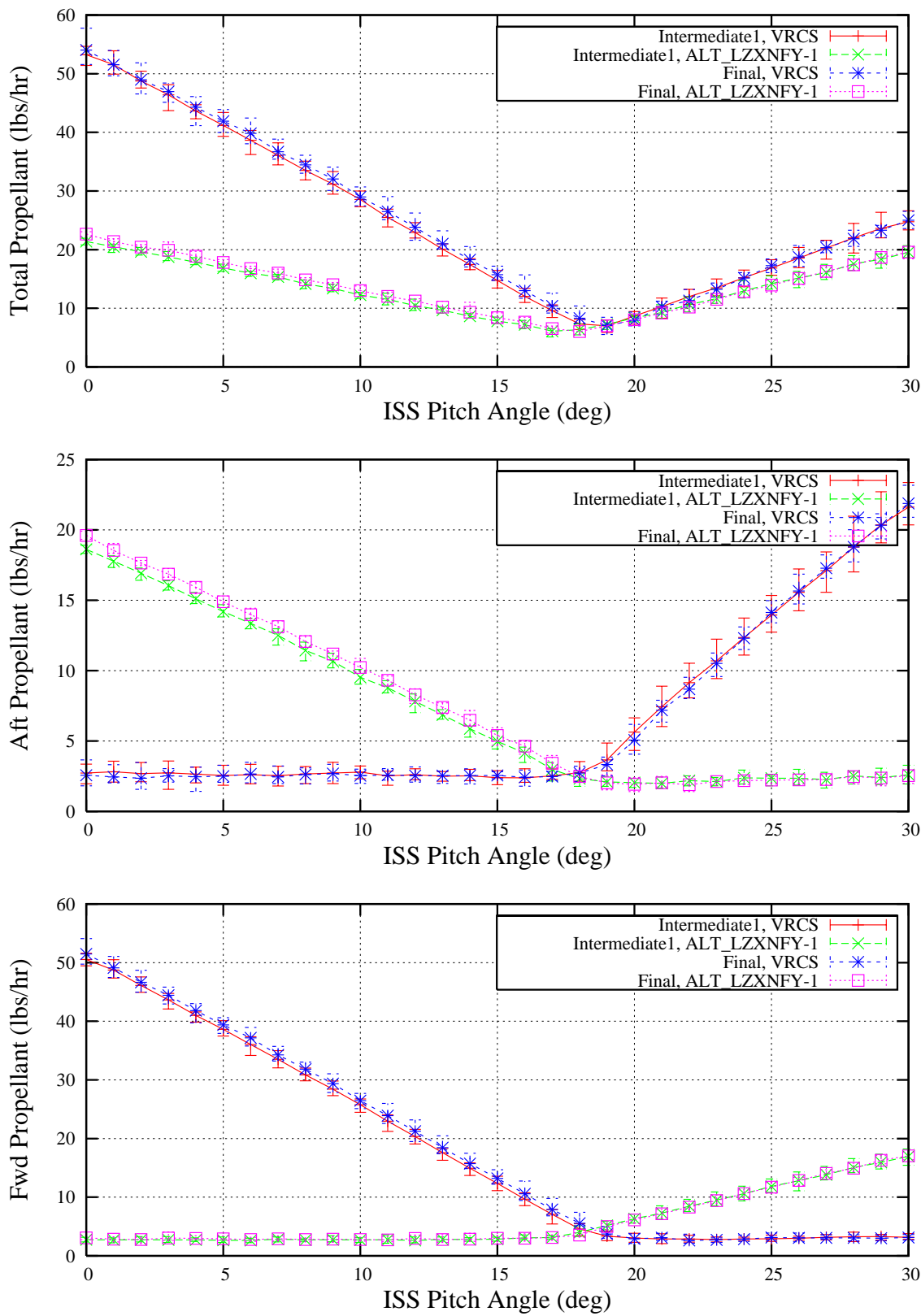


Figure 22: STS-128/17A Attitude Hold Propellant vs LVLH Pitch Angle, RxR ($y=180^\circ$, $r=0^\circ$)

17A RRR_HTV

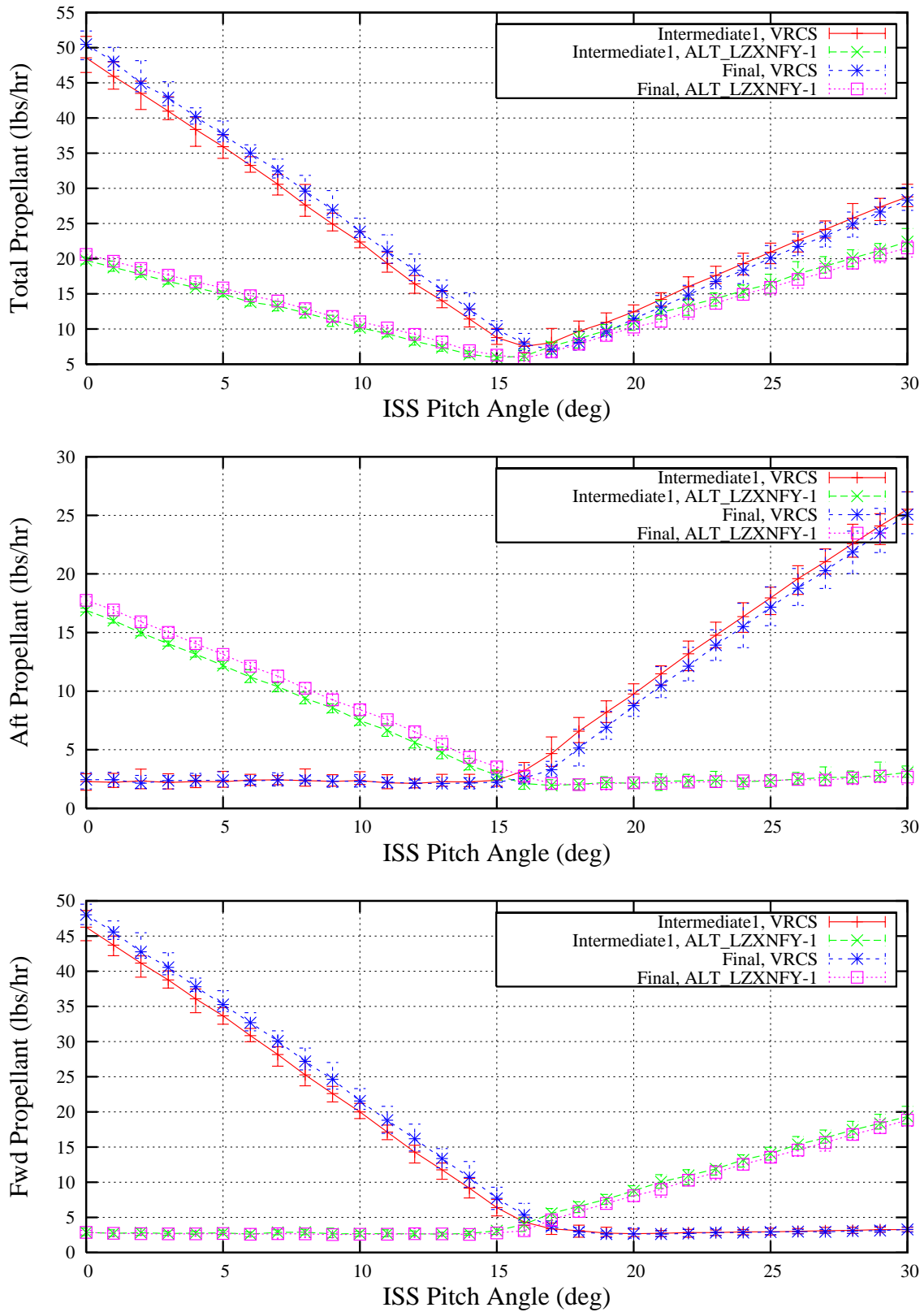


Figure 23: STS-128/17A Attitude Hold Propellant vs LVLH Pitch Angle, RRR HTV ($\gamma=180^\circ$, $r=0^\circ$)

17A RRx_HTV

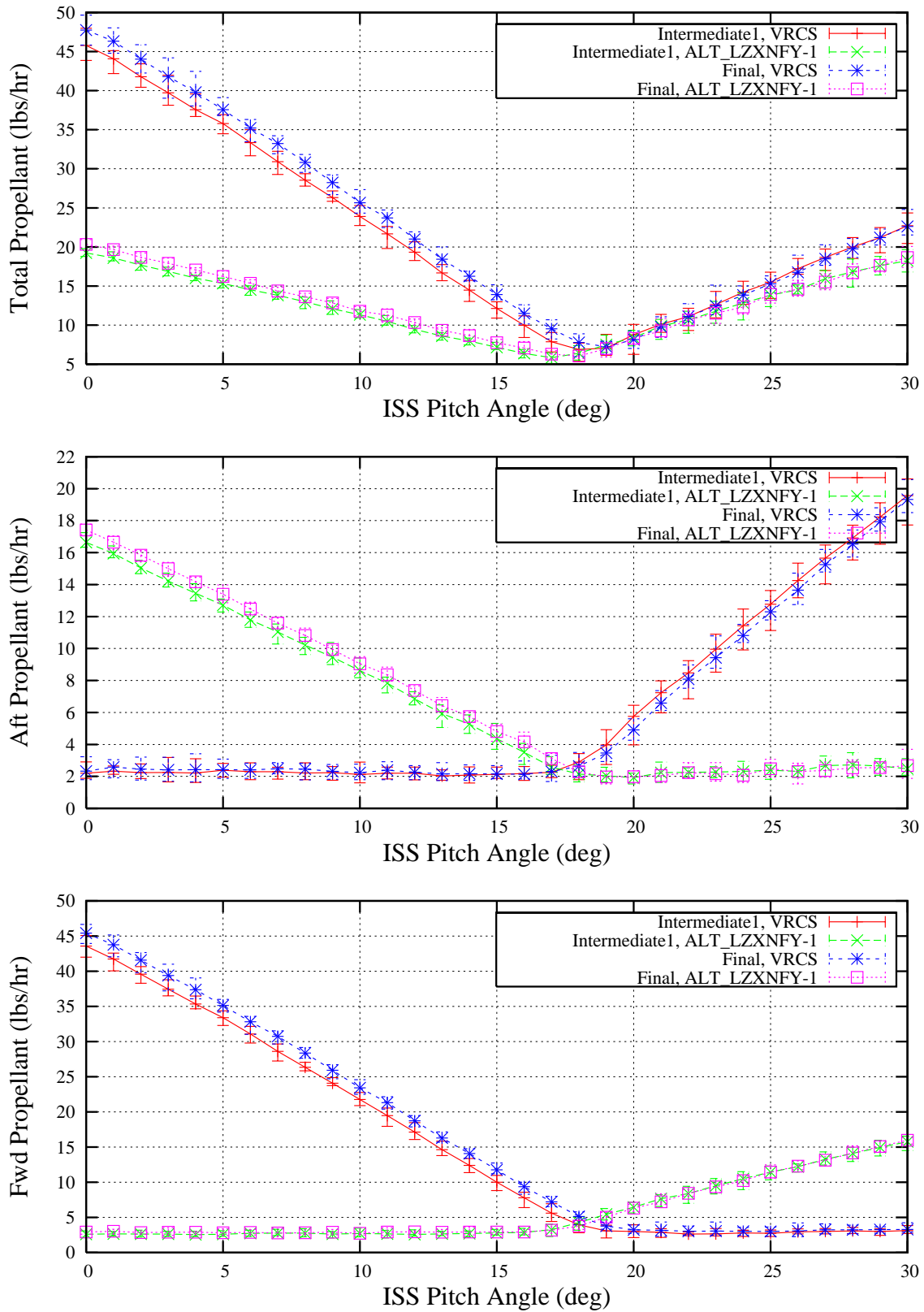


Figure 24: STS-128/17A Attitude Hold Propellant vs LVLH Pitch Angle, RRx HTV ($\gamma=180^\circ$, $r=0^\circ$)

17A RxR_HTV

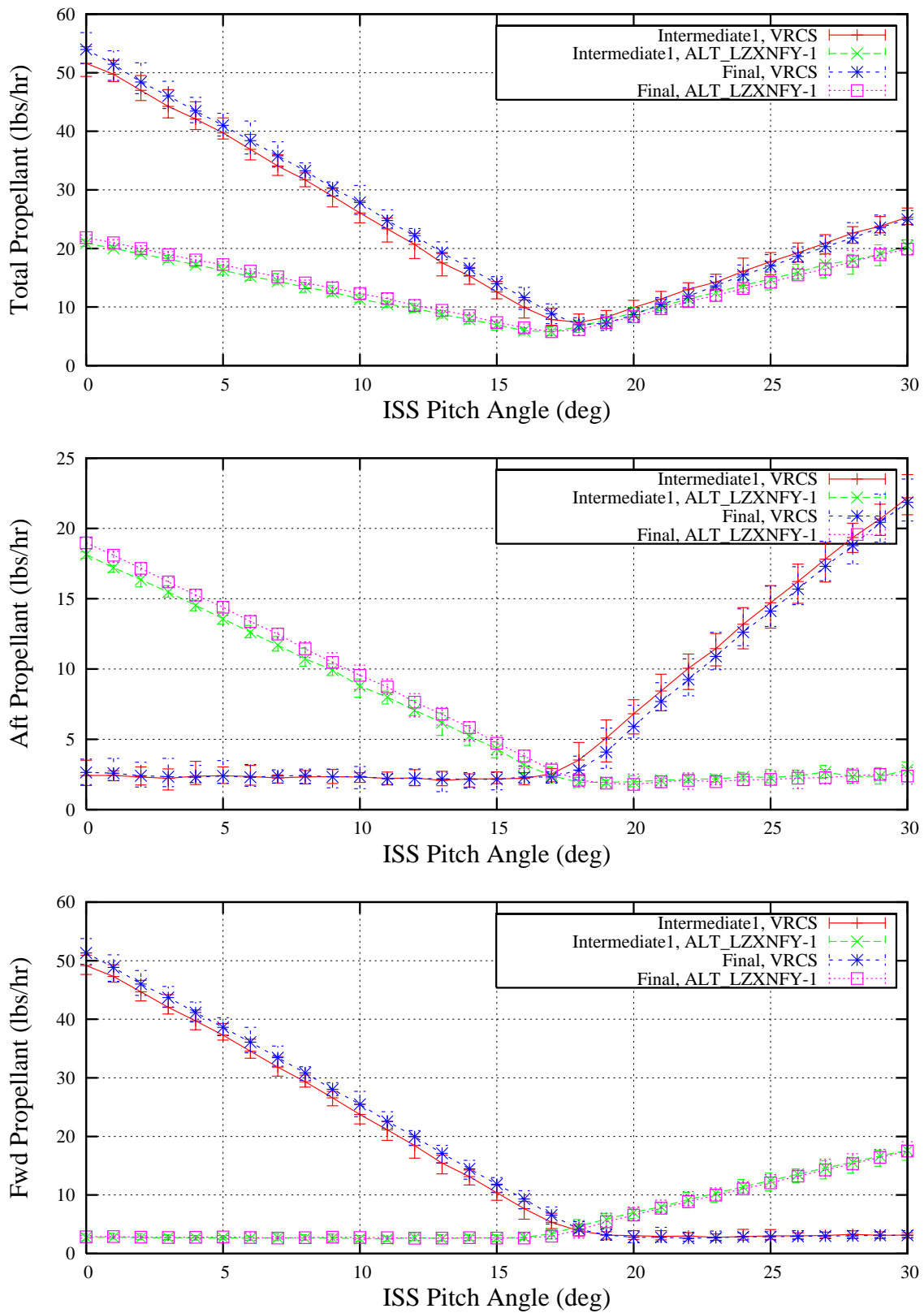


Figure 25: STS-128/17A Attitude Hold Propellant vs LVLH Pitch Angle, RxR HTV ($\gamma=180^\circ$, $r=0^\circ$)

Table 53: STS-128 Intermediate1 VRCS Propellant Usage, RRR (y=180°, r=0°)

LVLH Pitch Angle	Total			Aft			Forward		
	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)
0	48.16	50.16	52.81	1.68	2.57	3.86	46.48	47.59	49.51
1	44.62	47.73	50.66	1.76	2.55	3.85	42.68	45.18	46.80
2	44.11	45.48	48.57	2.09	2.67	3.93	41.60	42.81	45.17
3	41.77	43.22	44.96	2.31	2.78	3.50	38.99	40.44	41.46
4	38.60	40.58	42.88	2.27	2.69	3.68	36.32	37.89	39.20
5	34.97	37.34	39.33	1.86	2.52	3.05	32.89	34.82	36.34
6	32.96	34.81	37.81	2.01	2.60	3.64	30.65	32.21	34.17
7	30.75	32.49	33.50	2.14	2.76	3.03	28.16	29.73	30.49
8	28.28	29.44	31.86	1.83	2.52	3.33	25.71	26.92	28.55
9	25.37	26.60	27.79	2.12	2.61	3.56	22.85	23.99	24.86
10	21.71	23.75	25.55	2.00	2.55	2.98	19.41	21.20	22.64
11	20.19	21.07	22.31	2.29	2.56	2.96	17.47	18.51	19.57
12	16.82	18.26	19.65	1.99	2.52	2.87	14.55	15.74	16.79
13	13.72	15.31	16.33	2.23	2.40	2.60	11.45	12.91	13.91
14	11.27	12.68	14.22	2.00	2.44	2.88	8.68	10.24	11.43
15	9.10	10.24	12.02	1.97	2.52	2.86	6.38	7.72	9.16
16	6.96	7.97	9.82	2.06	2.74	3.24	4.53	5.22	6.58
17	5.72	6.97	8.49	2.58	3.33	3.88	3.11	3.64	4.78
18	6.72	7.99	9.10	4.37	5.15	6.13	2.16	2.84	4.17
19	9.01	10.03	11.25	6.26	7.23	8.15	2.27	2.80	3.33
20	10.43	11.60	12.55	7.90	8.98	9.87	2.36	2.62	3.13
21	12.51	13.68	15.34	9.80	10.87	12.13	2.35	2.80	3.39
22	14.31	15.48	16.47	11.56	12.64	13.50	2.35	2.84	3.28
23	16.40	17.29	18.34	13.40	14.38	15.34	2.63	2.91	3.19
24	18.25	18.95	20.03	15.00	16.03	16.96	2.61	2.92	3.35
25	19.29	20.53	21.28	16.59	17.60	18.46	2.66	2.93	3.33
26	21.11	22.61	24.06	18.19	19.44	20.66	2.88	3.17	3.62
27	22.08	24.42	25.69	19.42	21.08	22.04	2.66	3.34	4.48
28	24.65	25.74	27.25	21.43	22.56	23.96	2.81	3.19	4.09
29	25.60	27.29	28.94	22.70	24.04	25.30	2.89	3.26	3.71
30	27.64	29.09	30.68	24.21	25.76	27.18	3.00	3.32	3.73

Table 54: STS-128 Intermediate1 1-Jet ALT Propellant Usage, RRR (y=180°, r=0°)

LVLH Pitch Angle	Total			Aft			Forward		
	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)
0	19.78	20.30	20.86	17.29	17.55	17.87	2.41	2.74	3.07
1	18.54	19.28	19.82	16.22	16.66	16.96	2.32	2.62	2.99
2	17.58	18.29	18.83	15.22	15.72	16.05	2.20	2.57	3.03
3	17.00	17.29	17.96	14.60	14.79	14.97	2.16	2.50	3.15
4	16.17	16.55	17.17	13.60	13.92	14.39	2.36	2.63	2.86
5	15.26	15.53	15.84	12.81	12.98	13.27	2.32	2.55	2.86
6	13.98	14.64	15.30	11.74	12.08	12.28	1.99	2.56	3.07
7	13.15	13.87	14.64	10.70	11.24	11.69	2.20	2.63	3.15
8	12.61	13.02	13.60	9.79	10.28	10.58	2.36	2.73	3.03
9	11.36	12.04	12.98	8.67	9.29	10.20	2.32	2.75	3.32
10	10.70	11.05	11.65	8.00	8.34	8.87	2.61	2.71	2.78
11	9.37	10.16	10.74	7.01	7.46	7.71	2.28	2.70	3.11
12	8.46	9.10	9.91	5.97	6.49	7.01	2.24	2.61	3.19
13	7.38	8.14	8.92	4.52	5.46	6.10	2.07	2.68	3.11
14	6.51	7.21	7.84	3.77	4.47	5.14	2.12	2.73	3.36
15	5.64	6.26	6.97	2.99	3.43	4.06	2.36	2.83	3.15
16	5.52	6.15	6.68	2.20	2.70	3.11	2.65	3.44	4.31
17	6.10	6.85	7.59	1.99	2.37	2.74	3.69	4.48	5.02
18	6.84	7.94	8.71	1.70	2.20	2.78	4.85	5.74	6.51
19	8.29	9.14	10.08	1.91	2.22	2.57	6.05	6.92	7.63
20	9.50	10.28	11.49	1.91	2.23	2.65	7.09	8.05	9.17
21	10.28	11.33	12.40	1.82	2.20	2.78	7.92	9.14	10.08
22	11.49	12.81	13.56	2.03	2.45	2.82	9.46	10.36	11.16
23	12.86	13.96	15.18	1.87	2.57	2.94	10.53	11.39	12.40
24	14.27	15.07	16.13	2.03	2.48	2.74	11.69	12.59	13.40
25	15.05	16.21	17.87	1.74	2.53	3.23	12.65	13.68	14.64
26	16.13	16.96	18.29	2.07	2.52	2.94	13.56	14.44	15.34
27	17.33	18.15	18.87	2.12	2.53	3.07	14.51	15.62	16.55
28	18.25	19.78	20.94	2.20	2.89	3.57	15.34	16.89	17.67
29	19.45	20.74	21.98	2.41	2.90	3.44	16.63	17.84	18.66
30	20.86	21.67	22.98	2.53	3.09	4.06	17.46	18.59	19.24

Table 55: STS-128 Final VRCS Propellant Usage, RRR ($y=180^\circ$, $r=0^\circ$)

LVLH Pitch Angle	Total			Aft			Forward		
	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)
0	49.20	50.67	53.03	1.88	2.42	3.40	47.07	48.25	49.63
1	45.78	48.55	51.17	1.71	2.57	3.65	44.07	45.98	47.52
2	44.26	46.02	48.00	1.81	2.49	3.45	42.10	43.53	44.88
3	41.24	43.69	46.01	1.85	2.54	3.40	39.39	41.15	42.61
4	39.21	41.16	42.83	2.11	2.52	3.22	37.08	38.64	39.61
5	35.98	38.47	39.86	1.74	2.44	3.22	34.24	36.03	36.75
6	34.58	36.06	38.56	1.95	2.48	3.28	32.49	33.58	35.28
7	31.61	33.18	34.78	2.17	2.39	2.99	29.38	30.79	31.87
8	28.18	30.60	31.94	1.91	2.47	2.92	26.06	28.13	29.23
9	26.35	28.51	30.11	2.30	2.67	3.06	23.97	25.84	27.20
10	22.78	25.11	26.71	2.01	2.36	2.80	20.70	22.75	23.98
11	20.25	22.69	23.59	2.05	2.45	2.92	18.19	20.24	20.95
12	17.37	19.97	21.70	2.06	2.40	2.94	15.30	17.57	18.75
13	15.06	17.06	17.96	1.94	2.29	2.65	12.89	14.77	15.51
14	12.96	14.38	15.38	2.05	2.26	2.48	10.64	12.12	13.00
15	9.69	12.03	13.47	2.12	2.37	2.68	7.48	9.66	10.86
16	7.01	9.37	10.76	2.15	2.40	2.70	4.79	6.96	8.06
17	6.38	7.62	8.40	2.54	2.90	3.30	3.25	4.72	5.37
18	6.32	7.10	8.28	3.06	3.86	5.48	2.80	3.24	3.94
19	7.41	9.17	10.28	4.92	6.26	7.06	2.22	2.91	3.24
20	9.85	10.85	11.89	7.26	8.08	9.26	2.48	2.77	3.84
21	11.39	12.74	13.95	9.01	9.98	11.14	2.38	2.76	3.25
22	13.65	14.61	15.58	10.89	11.75	12.97	2.62	2.86	3.51
23	15.00	16.51	17.78	12.38	13.54	14.63	2.62	2.97	3.44
24	16.95	18.13	19.44	14.25	15.22	16.59	2.51	2.92	3.57
25	18.90	19.98	21.24	16.05	16.91	18.29	2.78	3.06	3.75
26	20.64	21.75	23.14	17.69	18.62	20.18	2.77	3.13	3.69
27	21.92	23.45	24.47	19.01	20.26	21.13	2.90	3.18	3.80
28	23.90	25.08	27.25	20.89	21.88	23.82	2.82	3.21	3.70
29	25.68	26.64	27.80	22.73	23.36	24.67	2.78	3.28	3.72
30	27.15	28.50	30.74	23.96	25.08	27.13	3.05	3.42	3.91

Table 56: STS-128 Final 1-Jet ALT Propellant Usage, RRR ($y=180^\circ$, $r=0^\circ$)

LVLH Pitch Angle	Total			Aft			Forward		
	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)	Min (lbs/hr)	Avg (lbs/hr)	Max (lbs/hr)
0	20.82	21.24	21.61	18.04	18.36	18.66	2.36	2.88	3.15
1	19.78	20.33	21.15	17.13	17.45	17.75	2.36	2.89	3.40
2	18.95	19.38	19.82	16.22	16.53	16.80	2.57	2.85	3.07
3	17.96	18.45	19.08	15.26	15.57	15.88	2.65	2.89	3.28
4	16.80	17.35	18.29	14.27	14.59	15.22	2.32	2.76	3.19
5	15.97	16.44	17.13	13.31	13.65	14.02	2.36	2.80	3.32
6	15.01	15.48	15.88	12.36	12.72	12.98	2.53	2.76	2.90
7	13.85	14.46	14.89	11.45	11.73	12.07	2.41	2.73	3.11
8	13.19	13.57	14.06	10.41	10.81	11.20	2.45	2.77	3.03
9	12.32	12.69	13.27	9.50	9.87	10.24	2.49	2.82	3.15
10	11.20	11.70	12.57	8.50	8.87	9.46	2.53	2.83	3.19
11	10.12	10.68	11.11	7.46	7.87	8.29	2.28	2.81	3.32
12	9.33	9.95	10.41	6.68	7.14	7.42	2.53	2.81	3.07
13	8.21	8.95	9.95	5.31	6.08	6.64	2.49	2.88	3.57
14	7.17	7.91	8.75	4.73	5.20	5.64	2.24	2.70	3.28
15	6.14	6.89	7.34	3.65	4.00	4.27	2.49	2.89	3.32
16	5.43	6.09	7.26	2.45	2.95	3.69	2.74	3.14	3.57
17	5.64	6.30	7.09	1.74	2.30	2.74	3.19	3.99	4.60
18	6.80	7.25	8.09	1.41	1.93	2.70	4.69	5.32	6.10
19	7.80	8.51	9.29	1.62	2.07	2.28	5.93	6.44	7.05
20	8.92	9.62	10.53	1.74	2.05	2.53	7.09	7.57	8.42
21	10.33	10.82	11.40	1.62	2.08	2.53	8.00	8.74	9.58
22	11.20	11.91	13.60	1.78	2.04	2.57	9.37	9.87	11.03
23	12.57	13.22	14.14	1.82	2.17	2.53	10.53	11.05	11.86
24	13.23	14.34	15.18	1.95	2.24	2.53	10.99	12.10	13.23
25	14.81	15.45	16.55	1.82	2.31	2.61	12.40	13.15	14.27
26	16.01	16.73	17.58	1.99	2.53	3.19	13.69	14.20	15.14
27	17.04	17.90	18.95	2.03	2.58	3.07	14.64	15.33	16.17
28	18.04	18.81	19.91	1.82	2.38	2.57	15.63	16.43	17.42
29	19.28	20.14	21.36	2.41	2.66	2.90	16.71	17.48	18.62
30	20.15	21.15	22.98	2.16	2.75	3.86	17.71	18.40	19.45

7.2 Random Attitude Holds with ALT

To test attitude hold capability with ALT, 10,000 random LVLH attitude holds were performed with dispersed mass properties ($\pm 1\%$ in inertia, ± 6 inches in center of mass), initial rate errors ($\pm 0.01^\circ/\text{sec}$), and modal uncertainties ($\pm 4\text{dB}$ amplitude, $\pm 20\%$ frequency). Figure 26 shows a histogram of the attitude errors for the Final RRR configuration. With the exception of a few outliers with large roll errors, the attitude errors are not large enough to trigger a maneuver. The maximum attitude and rate errors are shown in Table 57.

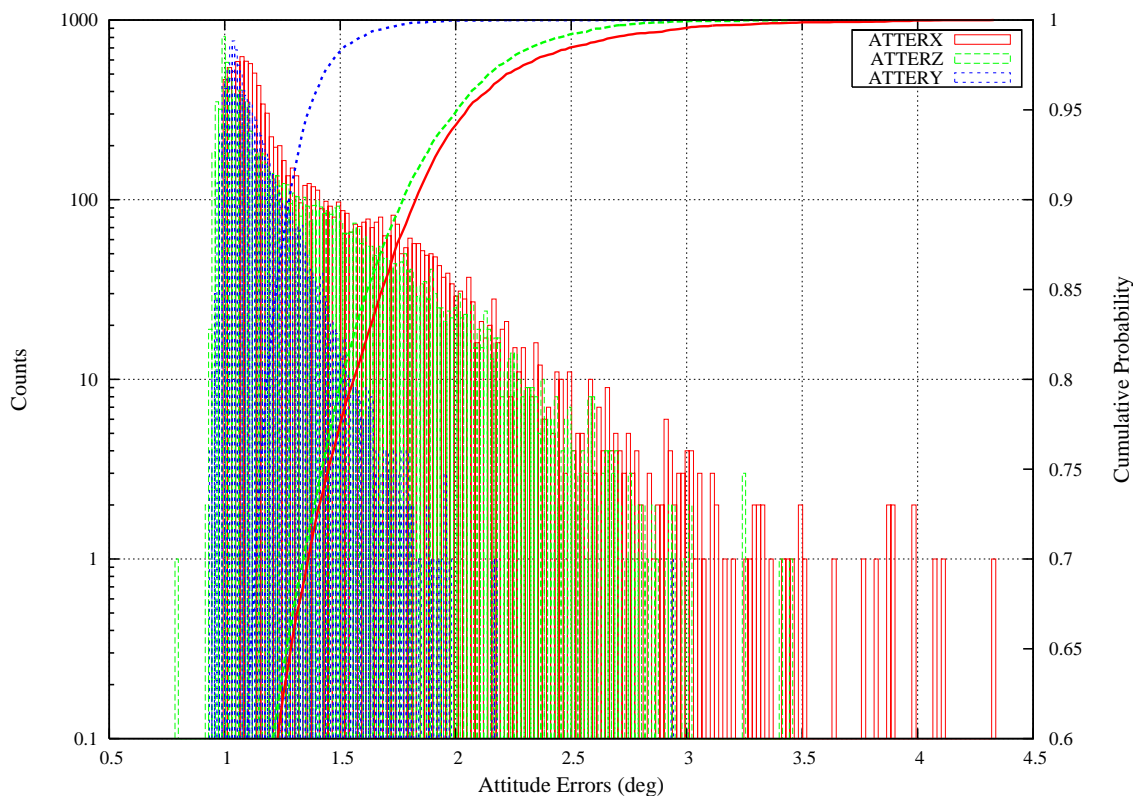


Figure 26: STS-128/17A ALT Random Attitude Hold Errors, Final RRR

Table 57: Maximum attitude and rate errors for random attitude holds for RRR

Config	Jet Mode	Max Attitude Error (deg)			Max Rate Error (deg/sec)		
		Roll	Pitch	Yaw	Roll	Pitch	Yaw
Inital	ALT	4.41	2.24	3.46	0.0192	0.0158	0.0178
Final	ALT	4.32	2.93	3.44	0.0204	0.0161	0.0179

7.3 Mission Specific Attitudes

All of the mission specific attitudes to be held under Orbiter control as documented in the July 22, 2009 Final ATL have been simulated and examined. Like the mission specific maneuvers, 100 cases with dispersed mass properties ($\pm 1\%$ in inertia, ± 6 inches in center of mass), initial rate errors ($\pm 0.01^\circ/\text{sec}$), and modal uncertainties ($\pm 4\text{dB}$ amplitude, $\pm 20\%$ frequency) were run for each mission specific attitude. Results using the attitude hold DAP are summarized in Table 58. The table shows the Orbiter body attitudes relative to LVLH which are expressed by a PYR Euler angle sequence given in RPY order. In comparison, attitude hold with the *maneuver* DAP can use up to three times as much propellant, as shown in Table 59. Note that the attitude hold DAP is required at the undocking attitude. The maximum attitude and rate errors during attitude hold are shown in Table 60. The ΔV from the mission-specific holds is shown in Tables 61 and 62.

Table 58: Estimated attitude hold propellant usage with the attitude hold DAP for selected ATL events for RRR

ATL Attitude	Total lbs/hr	1σ lbs/hr	Aft lbs/hr	1σ lbs/hr	Fwd lbs/hr	1σ lbs/hr
30: 170.99 73.55 4.80 – Bias –XVV Mated TEA						
ALT lzxnfy-1	5.30	0.52	2.70	0.42	2.60	0.49
VRCS	6.06	0.87	1.88	0.35	4.18	0.86
31: 168.10 73.82 5.64 – Water Dump						
ALT lzxnfy-1	5.42	0.53	2.42	0.36	3.00	0.52
VRCS	5.37	0.66	2.06	0.40	3.31	0.63
32: 170.91 74.54 4.64 – Bias –XVV Mated TEA						
ALT lzxnfy-1	5.47	0.40	3.36	0.36	2.11	0.38
VRCS	7.25	0.85	1.56	0.33	5.69	0.81
33: 0.00 90.00 0.00 – Undock Attitude						
ALT lzxnfy-1	22.40	0.82	18.84	0.29	3.56	0.60
VRCS	53.93	1.18	3.30	0.37	50.63	0.97

Table 59: Estimated attitude hold propellant usage with the *maneuver* DAP for selected ATL events for RRR

ATL Attitude	Total lbs/hr	1σ lbs/hr	Aft lbs/hr	1σ lbs/hr	Fwd lbs/hr	1σ lbs/hr
30: 170.99 73.55 4.80 – Bias –XVV Mated TEA						
VRCS	15.66	2.41	6.69	1.28	8.97	1.41
31: 168.10 73.82 5.64 – Water Dump						
VRCS	14.77	2.30	6.46	1.28	8.31	1.35
32: 170.91 74.54 4.64 – Bias –XVV Mated TEA						
VRCS	15.45	2.12	6.20	1.06	9.25	1.26
33: 0.00 90.00 0.00 – Undock Attitude						
VRCS	55.28	2.00	4.59	0.78	50.69	1.39

Table 60: Maximum attitude and rate errors for mission-specific attitude holds for RRR

DAP	Jet Mode	Max Attitude Error (deg)			Max Rate Error (deg/sec)		
		Roll	Pitch	Yaw	Roll	Pitch	Yaw
B12	VRCS	1.04	1.07	1.02	0.0106	0.0121	0.0112
B12	ALT	1.33	1.26	1.21	0.0108	0.0120	0.0108
A12	VRCS	3.06	3.23	3.03	0.0117	0.0200	0.0144

Table 61: Estimated ΔV for selected ATL attitudes using attitude hold DAP for RRR

ATL Attitude	ΔV_x (ft/sec/hr)	ΔV_y (ft/sec/hr)	ΔV_z (ft/sec/hr)	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
					Total	Fwd	Aft
30: 170.99 73.55 4.80 – Bias –XVV Mated TEA							
ALT lzxnfy-1	0.009	-0.002	0.004	110.640	607	299	308
VRCS	0.031	0.005	0.009	32.087	195	133	62
31: 168.10 73.82 5.64 – Water Dump Attitude							
ALT lzxnfy-1	0.007	-0.001	0.010	136.096	806	454	352
VRCS	0.026	0.006	0.007	37.925	204	125	79
32: 170.91 74.54 4.64 – Bias –XVV Mated TEA							
ALT lzxnfy-1	0.010	-0.000	-0.004	99.213	553	211	343
VRCS	0.039	0.007	0.011	25.764	187	146	41
33: 0.00 90.00 0.00 – Undock Attitude							
ALT lzxnfy-1	0.005	-0.004	-0.134	185.985	17908	3269	14640
VRCS	-0.344	-0.025	0.007	2.907	157	147	10

Table 62: Estimated ΔV for selected ATL attitudes using *maneuver* DAP for RRR

ATL Attitude	ΔV_x (ft/sec/hr)	ΔV_y (ft/sec/hr)	ΔV_z (ft/sec/hr)	Time per ΔV_x (hr/(ft/sec))	Prop per ΔV_x (lbs/(ft/sec))		
					Total	Fwd	Aft
30: 170.99 73.55 4.80 – Bias –XVV Mated TEA							
VRCS	0.075	0.014	0.018	13.248	208	119	89
31: 168.10 73.82 5.64 – Water Dump Attitude							
VRCS	0.070	0.018	0.017	14.268	211	119	92
32: 170.91 74.54 4.64 – Bias –XVV Mated TEA							
VRCS	0.075	0.015	0.018	13.285	206	123	82
33: 0.00 90.00 0.00 – Undock Attitude							
VRCS	-0.344	-0.028	-0.003	2.909	161	147	13

8 OBSS and Orbiter-Alone Operations

8.1 Non-Mated Operations

8.1.1 OBSS TPS Inspections

The deadband and rate limits for operations with the OBSS extended on the SRMS are constrained by NSTS 07700, Volume XIV, Appendix 8 [15]. For RMS maneuvers with a lightly-loaded arm, the VRCS rate limit is limited to be no less than 0.2 degrees/second, and the deadband no less than 3 degrees.

Single-jet ALT-Tail mode is acceptable for OBSS attitude hold during inspection operations (in the absence of vernier capability), but deadband and rate-limit modifications are required for the same reason as described above. For ALT mode, a deadband of 5 degrees and a rate-limit of 0.2 degrees/second are required. A minimum-impulse ALT on-time and a 6 second ALT delay are required when the OBSS sensors are collecting data. This is done with the intent to minimize the interference from jet activity during data collection.

For Orbiter attitude maneuvers with the OBSS deployed on the SRMS, a 2-jet ALT-mode is required, to reduce jet-pulsing and to provide improved maneuver performance over that of the 1-jet ALT-mode.

8.1.2 Non-Survey Activity (OBSS Extended)

In general, Orbiter-alone operations with the OBSS on the SRMS do not pose attitude control or stability problems. Exceptions to this might be found at extreme extensions of the OBSS, or at very tight (uncertified) deadbands and rate limits. Although the OBSS is a relatively light payload, it has a large center-of-mass displacement, and may not fall within the bounding assumptions for generic payloads.

Although the RMS/OBSS extension does not, in general, raise control or stability concerns, other technical disciplines depend on forcing-function data from EG/Draper for their certification. Such data have only been provided for specific RMS angles and under specific DAP conditions.

Two different RMS/OBSS positions have been analyzed at various stages of undocking and separation. The joint angles for these 2 positions are:

RMS Position	SHY	SHP	ELP	WRP	WRY	WRR
Undock	25.8	66.3	-49.0	-85.9	10.7	-100.7
Expedited Undock	95.0	38.7	-22.8	-0.5	-0.3	-68.0

The phases of undocking and separation which have been analyzed and accepted for these 2 arm positions (from a flight control perspective) are summarized in the table below:

RMS Position	Undocking	Sep1	Sep2	Flyaround
Undock	OK	OK	OK	OK
Expedited Undock	OK	OK		

8.1.3 Contingency: Loss of a side-firing Vernier Jet – non-mated operations

For non-mated Orbiter attitude control, the loss of a side-firing vernier jet does not cause loss of control. However, for certain critical operational phases, attitude control in 5-jet mode is either undesirable or not certified, as indicated below.

- Certified:
 - Orbiter-alone attitude control
 - OBSS TPS surveys
- Not certified:
 - Rbar Pitch Maneuver (RPM)
 - Rendezvous

8.2 Mated OBSS TPS Surveys

Mated OBSS operations, with SRMS or SSRMS, are not a concern from an attitude-control point of view, because of the large inertia of the base-body and the small payload mass. However, procedures written for unmated operations may not be appropriate while mated. For example, tail-only PRCS control for Orbiter-alone is a standard control mode; but for current Orbiter/ISS mated configurations, tail-only PRCS control is not a viable option.

A Acronyms and Abbreviations

ALT	Abbreviation for <i>Alternate Primary Mode</i>
APU	Auxiliary Power Unit
ATA	Ammonia Tank Assembly
ATL	Attitude Time Line
ATV	Automated Transfer Vehicle
CAMMP	Configuration Analysis Modeling and Mass Properties
CBM	Common Berthing Mechanism
CMG	Control Moment Gyro
DAP	Digital Autopilot
DC1	Docking Compartment 1
EuTEF	European Technology Exposure Facility
FCS	Flight Control System
FES	Flash Evaporator System
FGB	Functional Cargo Block
GPC	General Purpose Computer
HEV	Hatch Equalization Valve
HTV	H-II Transfer Vehicle
I-Load	Initialization Load
ICD	Interface Control Document
IMU	Inertial Measurement Unit
ISS	International Space Station
LVLH	Local Vertical Local Horizontal
MBS	MRS (Mobile Remote Servicer) Base System
MCA	Magnitude of Control Acceleration
MPLM	Multi-Purpose Logistics Module
MRM2	Mini Research Module-2
MT	Mobile Transporter
OA	I-Load Occurrence type used for mass property and notch filter I-Loads
OBSS	Orbiter Boom Sensor System
ODS	Orbiter Docking System
OI	Operational Increment
PBI	Push Button Indicator
PDGF	Power and Data Grapple Fixture
POA	Payload Orbital Replacement Unit (ORU) Accommodation
PRCS	Primary Reaction Control System (870 lbf jets)
PYR	Pitch-Yaw-Roll
RMS	Remote Manipulator System
RPM	Rbar Pitch Manuever or Revolutions per Minute
RPY	Roll-Pitch-Yaw
RRR	Russian vehicle docked to FGB port, Russian vehicle at DC1 nadir, and Russian vehicle at SM aft
RRx	Russian vehicle docked to FGB port, Russian vehicle at DC1 nadir, and nothing at SM aft
RxR	Russian vehicle docked to FGB port, no vehicle at DC1 nadir, and Russian vehicle at SM aft
SM	Service Module
SODB	Shuttle Operational Data Book
SRMS	Shuttle Remote Manipulator System
SSRMS	Space Station Remote Manipulator System
STS	Space Transportation System

TEA	Torque Equilibrium Attitude
TPS	Thermal Protection System
USTO	US Segment Thrusters Only (attitude control mode)
VRCS	Vernier Reaction Control System (24 lbf jets)
WS	Workstation
WSB	Water Spray Boiler

B References

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