

EMU Lessons Learned Database

Kevin Matthews

Johnson Space Center

Major: Electrical and Computer Engineering

USRP Fall 2011

Date: 09 Dec. 2011

EMU Lessons Learned Database

Kevin M. Matthews Jr.¹ and Lori Crocker²
NASA Johnson Space Center, Houston, TX, 77058

J. Scott Cupples³
NASA Johnson Space Center, Houston, TX, 77058

As manned space exploration takes on the task of traveling beyond low Earth orbit, many problems arise that must be solved in order to make the journey possible. One major task is protecting humans from the harsh space environment. The current method of protecting astronauts during Extravehicular Activity (EVA) is through use of the specially designed Extravehicular Mobility Unit (EMU). As more rigorous EVA conditions need to be endured at new destinations, the suit will need to be tailored and improved in order to accommodate the astronaut. The Objective behind the EMU Lessons Learned Database (LLD) is to be able to create a tool which will assist in the development of next-generation EMUs, along with maintenance and improvement of the current EMU, by compiling data from Failure Investigation and Analysis Reports (FIARs) which have information on past suit failures. FIARs use a system of codes that give more information on the aspects of the failure, but if one is unfamiliar with the EMU they will be unable to decipher the information. A goal of the EMU LLD is to not only compile the information, but to present it in a user-friendly, organized, searchable database accessible to all familiarity levels with the EMU; both newcomers and veterans alike. The EMU LLD originally started as an Excel database, which allowed easy navigation and analysis of the data through pivot charts. Creating an entry requires access to the Problem Reporting And Corrective Action database (PRACA), which contains the original FIAR data for all hardware. FIAR data are then transferred to, defined, and formatted in the LLD. Work is being done to create a web-based version of the LLD in order to increase accessibility to all of Johnson Space Center (JSC), which includes converting entries from Excel to the HTML format. FIARs related to the EMU have been completed in the Excel version, and now focus has shifted to expanding FIAR data in the LLD to include EVA tools and support hardware such as the Pistol Grip Tool (PGT) and the Battery Charger Module (BCM), while adding any recently closed EMU-related FIARs.

Nomenclature

<i>EVA</i>	=	Extravehicular Activity
<i>EMU</i>	=	Extravehicular Mobility Unit
<i>EMU LLD</i>	=	EMU Lessons Learned Database
<i>BCM</i>	=	Battery Charger Module
<i>EHIP</i>	=	EVA Helmet Interchangeable Portable Lights
<i>REBA</i>	=	Rechargeable EVA Battery Assembly
<i>SPCE</i>	=	Service Performance Checkout Equipment
<i>SAFER</i>	=	Simplified Aid For EVA Rescue
<i>PGT</i>	=	Pistol Grip Tool
<i>PRACA</i>	=	Problem Reporting and Corrective Action Database
<i>FIAR</i>	=	Failure Investigation and Analysis Report
<i>JSC</i>	=	Johnson Space Center

¹ Undergraduate Student Research Program Intern, EVA Office, Johnson Space Center, The Ohio State University.

² Chief Engineer, EVA Office, Mail Stop – XA, Johnson Space Center.

³ Hardware Development Engineer, EVA Office, Mail Stop - XA, Johnson Space Center.

I. Introduction

Manned spaceflight first began with the successful orbit of Soviet Cosmonaut Yuri Gagarin on April 12th, 1961¹, ushering in a bold new age of exploration on the grand frontier of space. On February 20th, 1962, Astronaut John Glenn became the first American to successfully orbit the Earth as part of the Mercury project². Through 1965, both nations proved that man could be put in orbit and brought back safely, but the question remained of how a human would fare in the space environment. The question was answered in 1965, when Alexei Leonov and Ed White II became the first Soviet and American, respectively, to perform a spacewalk, or EVA^{3,4}. Since then, EVA has become a crucial routine function during space missions, from repairing the Hubble Space Telescope⁵, to assembling the International Space Station⁶. Spacesuits and tools used have changed drastically since that time, improving in order to maximize the amount of time an astronaut can spend on an EVA, and to meet the required tasks. The EMU has become the main spacesuit of choice for EVA since debuting in 1983 on STS-6⁷.

In a twenty-nine year period, many changes have been made and lessons have been learned in regards to design and maintenance of the EMU and EVA support hardware. Every time a failure occurred, a FIAR was filled out in order to document the nature of the failure, and the corrective action taken. FIARs are kept in a database known as PRACA which contains all of the information from the FIAR, along with the original scanned document. While the information is available, it is unorganized and the codes used to describe the failure are undefined or obsolete, and thus, based on the amount of time someone has worked with the EMU, the data can be hard to interpret. The objective of the EMU LLD is to compile information from EMU and EVA tool FIARs in an organized user-friendly interface which accommodates all familiarity levels with the EMU, and allows analysis, on a large and small scale, of past failures to aid in any future EMU or EVA tool design.

II. EMU LLD Work History

The EMU LLD was started by Jake Baker in 2009. It was developed in Excel with the intent of compiling data from FIARs related specifically to EMU hardware. Original work included establishing a format for the database, along with entering the first EMU Hardware entries. In 2010 work was started by Samantha McCue to create a web-based version of the database in order to expand accessibility to the EMU LLD throughout JSC. Web-database work included coming up with a design for the website, keeping user-friendliness in mind, along with coding the features, and finally transferring entries from the Excel version of the LLD, to the website.

III. EMU LLD Structure

The Excel database is made up of the “Text” “All” and “Parts” pages, each with specific information. The “Parts” page contains more information about the specific components in the hardware that experienced failure; including the serial/lot number, the report number, and the date of the failure. The “All” page has more in-depth information from the FIAR, including the PRACA trend codes. The trend codes were originally used as a system to quickly give information regarding the failure. Codes were in place to describe the operation in place when the failure occurred, where it happened, what happened, and what part was affected among some examples. The “All” page includes most of the original information off of the FIAR along with dates. The “Text” page contains simplified information on the components, the failure and corrective action, using both text and a graphical representation to organize the data. Every entry in the database has data on each page of the excel sheet, including the related FIAR number, which overall gives a very detailed view in to the nature of the failure which is easily understood, and easy to navigate.

A. Parts

The text page contains fields for the FIAR number, which is assigned to every FIAR based on the location and chronological order of the FIAR, the part number which specifies the hardware that failed, and then the serial/lot number which specifies the exact piece of hardware which failed, or production lot in the case of a production-based error.

1	Report No.	NSTS Part No	Nomenclature	Serial/Lot #	Detect Date
375		EV032676-1	EMU LITHIUM ION BATTERY CHARGER	5002	
	JSCFP0233	EV032676-1	EMU LITHIUM ION BATTERY CHARGER	1004	
376		EV032676-2	EMU LITHIUM ION BATTERY CHARGER	1006	1/27/2006
	JSCFP0232	EV032656-1	BATTERY, LITHIUM ION ASSY	1010	
378	JSCFP0235	EV032676-2	EMU LITHIUM ION BATTERY CHARGER	1005	2/2/2006
379		EV032676-2	EMU LITHIUM ION BATTERY CHARGER	1006	2/8/2006
380		EV832986-1	LCD DISPLAY MODULE	N/A	
381					

Figure 1. “Parts” Page. Contains specific information on components involved in failure

NASA USRP – Internship Final Report

	L	M	N	O	P	Q	R	S	T	U	V
1	Process Escap	Location Code	Material Code	Test Op Code	Prevail Cond Co	Failure Mode Co	Defect Code	Cause Code	Recur Ctrls Code	Remarks	Days Open
295	NO	JSC - JOHNSON SPACE CENTER	Z - NO MATERIAL DEFECT APPLIES	AI - ACCEPTANCE TEST	F - OBSOLETE --- FUNCTIONAL	EQ - OBSOLETE --- OUTPUT PRESENT	EP - ELECTRICAL VALUE OF ITEM	D - DESIGN - WHEN NO MORE	0 - EXPLANATION RATHER THAN		5
296	NO	FLT - FLIGHT	XU - MATERIAL UNKNOWN -	F - FLIGHT (PERIOD)	F - OBSOLETE --- FUNCTIONAL	EAF - FAILS OFF	XU - DEFECT UNKNOWN -	UF - UNEXPLAINED ANOMALY IN	0 - EXPLANATION RATHER THAN		18
297	NO		Z - NO MATERIAL DEFECT APPLIES	Q - QUALIFICATION OR	V - VIBRATION FUNCTIONAL	EED - OBSOLETE --- OUTPUT DATA	DB - DAMAGED SHAPE - BENT,	DH - HARDWARE DESIGN	1 - DESIGN CHANGE		46
298	NO	JSC - JOHNSON SPACE CENTER	N - HOLE, NOZZLE, ORIFICE, OR VENT,	Q - QUALIFICATION OR	F - OBSOLETE --- FUNCTIONAL	UC - UNSATISFACTOR	MC - CLEARANCE EXCESSIVE OR	DH - HARDWARE DESIGN	0 - EXPLANATION RATHER THAN		81
299	NO		E - ELECTRICALLY CONDUCTING	Q - QUALIFICATION OR	L - LIFE TEST	EC - PREMATURE OR INADVERTENT	DB - DAMAGED SHAPE - BENT,	ES - EMI - SHIPPING	2 - MANUFACTURING		25
300	NO		A - ELECTRICAL CIRCUIT	MI - MANUFACTURING	F - OBSOLETE --- FUNCTIONAL	EQ - OBSOLETE --- OUTPUT PRESENT	MW - MISWIRED OR MISROUTED	MA - OBSOLETE --- MANUFACTURING	0 - EXPLANATION RATHER THAN		229
301	NO		K - ADHESIVE, CHEMICAL BOND,	AI - ACCEPTANCE TEST	V - VIBRATION	EN - OPEN, HIGH RESISTANCE,	DD - DAMAGED - MATERIAL	MAT - OBSOLETE - EQUIPMENT OR	2 - MANUFACTURING		393
302	NO	HSSI	Z - NO MATERIAL DEFECT APPLIES	Q - QUALIFICATION OR	L - LIFE TEST	EL - SHORT, LOW RESISTANCE, LOW	ML - DEGRADED BY AGE,	DHC - HARDWARE DESIGN - LIFE	0 - EXPLANATION RATHER THAN	THE EXTENSION IS NEEDED UNTIL A	118
303	NO	USA	F - ENCAPSULATION,	AI - ACCEPTANCE TEST	N - INSPECTION (NOT	UC - UNSATISFACTOR	DD - DAMAGED - MATERIAL	MI - MANUFACTURING	2 - MANUFACTURING		21
304	NO	JSC - JOHNSON SPACE CENTER	Z - NO MATERIAL DEFECT APPLIES	PL - FIELD DETECTED -	F - OBSOLETE --- FUNCTIONAL	MP - FAILS OPEN OR FAILS TO APPLICABLE	XN - NO DEFECT APPLICABLE	DH - HARDWARE DESIGN	0 - EXPLANATION RATHER THAN		2
305	NO	JSC - JOHNSON SPACE CENTER	S - STRUCTURAL ELEMENT(S) OR	AI - ACCEPTANCE TEST	F - OBSOLETE --- FUNCTIONAL	MIMB - BINDING, OR	MA - MECHANICALLY	DH - HARDWARE DESIGN	1 - DESIGN CHANGE		161

Figure 2. "All" Page. Contains trend codes from PRACA. Shown "expanded"

B. All

The "All" page contains information from the FIAR such as the FIAR number, title of the problem, a short description of the problem, the dates, the criticality, and trend codes. The title of the problem and the description give a short summary of the failure that occurred, whereas criticality relates to the potential outcome of the failure, broken down in to "Crit 1," "Crit 2," and "Crit 3." Crit 1 failures result in the loss of life, or vehicle, "Crit 2" failures result in a loss of mission, and "Crit 3" contains all other failures. Criticality has letter codes that can be added to the crit classification which signify levels of redundancy or other special circumstances. Finally, the trend codes are taken from PRACA and expanded out from their original form in order to define their meaning. The trend codes are undefined in PRACA and on the original FIAR documents, originally needing a PRACA code table to look up the meaning. In the EMU LLD these codes are defined so that no further documentation is required, allowing all information in the database to be easily interpreted for all familiarity levels.

	A	B	C	D	O	P	Q	R	S	T	U	V
1	Report No.	Resolve Element	Closure Text	Summary	In Develo.	In Manuf.	In Repair	In Test/ls	In Operat.	Class I or II	Class III Ha	Fr
275	JSCER0046	CAIP Closeout Statement	Troubleshooting / Analysis and Results	3/17 boards failed to meet the humid acceptance test requirement. Cause				X		X		
276	JSCER0047	Explanation Rationale	Troubleshooting / Analysis and Results	Dark stripes on part of staking that contacted silver plated wire, similar				X		X		
277	JSCER0050	CAIP Closeout Statement	Troubleshooting / Analysis and Results	During post vibration functional test battery's parameters were not				X		X		
278	JSCER0055	Remedial Action	Troubleshooting / Analysis and Results	Voltage, current, and temperature readings on battery after post-				X		X		
279	JSCER0061	Remedial Action	Troubleshooting / Analysis and Results	During post-vibration performance test string 3 of SAFER battery showed n				X		X		
280	MMU00031	NONE	RESULTS OF ANALYSIS:	Low voltage observed during first c of thermal vacuum test. Specificatio				X			X	
281	MMU00032	NONE	RESULTS OF ANALYSIS:	Batteries exhibited open circuit at the current pulse test. 4.5 minute randor				X			X	
282	MMU00035	NONE	RESULTS OF ANALYSIS:	After battery was pressurized to 55 psig for 5 minutes, case deformation				X			X	
283	MMU00036	NONE	RESULTS OF ANALYSIS:	End cell vent hole had thread damage first two threads. Hardware cover				X			X	
284	MMU00049	NONE	RESULTS OF ANALYSIS:	Binding noted between battery hinge brackets and mating clevis portion o				X			X	
285	MMU00242F	NONE	ANALYSIS:	Battery thermal cover came open du shrinkage. Caused by degradation o					X		X	

Figure 3. "Text" Page. Information split with written and visual information

C. Text

The text page is the result of combining all of the data from "All" and "Parts" to a single page in a written and visual representation. Component information is broken down by system, and component, to the specific

K	L	M	N
Found	Class	Failure	Solution
In Operation	Class I or II, Flight Crew/Ground	Electrical Anomaly	No Action (see details)
In Operation	Class I or II, Flight Crew/Ground	Expected wear, Expired Hardware, Design Error	Procedure Change
In Testing/Processing	Class I or II, Flight Crew/Ground	Design Error	Replaced Hardware
In Operation	Class III, Flight Crew/Ground	Unknown	No Action (see details)
In Testing/Processing	Class I or II, Flight Crew/Ground	Excessive Load, Expected Wear	Procedure Change, Train/Notify
In Testing/Processing	Class I or II, Flight Crew/Ground	Design Error	No Action (see details)
In Testing/Processing	Class I or II, Flight Crew/Ground	Human Error, Manufacturing Error	Procedure Change, Manufacturing
In Manufacturing	Class I or II, Flight Crew/Ground	Manufacturing Error, Design Error	Design New Hardware, Replaced
In .. .	Class I or II, Flight .. .	Manufacturing Error, .. .	Repaired Hardware, .. .

Figure 4. "Bucket Categories." Also represented visually.

The last 4 categories, in Figure 4, correspond to the “Bucket Categories” which are graphed on the adjacent side of the spreadsheet. These include information on the process in which the failure occurred, for example, testing, manufacturing, or repair; classification of the hardware, divided in to Class I or II and Class III; the cause of failure, such as incorrect handling or errors in design; and corrective action taken, such as repairing hardware, or updating the firmware or software. The visual representation gives an organizing factor to the information, where a column could be sorted through to find FIARs related to the desired category, instead of having to sort through the different textual fields.

D. Creating An Entry

FIAR data come from the PRACA online resource, also available as a Microsoft Access database, which allows FIARs to be searched and sorted through in multiple categories such as: System, date, part number, and part name. Hardware is typically added in groups for better organization in the database. The process for adding hardware can be broken down in to a sequence of steps:

1. Transfer the Parts List information from PRACA in to the “Parts” tab
2. Transfer the dates, problem title, and description from PRACA to the “All” page.
3. Transfer the criticality over from PRACA; “expand” the code by inserting the definition from the PRACA code tables after a hyphen following the number code.
4. Transfer over the Location and Trend Codes from PRACA; “expand” the code by inserting the definition from the PRACA code tables after a hyphen following the code.
5. Transfer resolving element, dates, component information and class to “Text” page.
6. Format the Closure Text in chronological order; space out to make it easier to read. Transfer Closure text.
7. Use the Problem Description and the Closure Text in order to write a concise summary which covers the failure, the cause, and corrective action in fewer than 400 words.
8. From the information gathered, classify the failure in the “Bucket Categories”; mark the applicable boxes in the graph and record the category in the corresponding text box.

Each entry utilizes the information from PRACA, although the formatting and organization is unique to the EMU LLD which allows greater control over the data for desired analysis.

item that caused the failure. The page has unique elements in the “Bucket Categories” on the right portion, which allow visual overview of problems to identify trends and see where and how problems occurred, and what action was taken to correct the problem.

The Closure Text from the FIAR is also located on this page, which gives in-depth information on topics such as the Troubleshooting and Analysis process, the Root Cause, and the Corrective Action taken.

A summary is written for every entry and included on this page, which is kept under 400 words, and includes the problem, the cause of the problem, and the corrective action. The summary grants the ability to get an overview of the FIAR in a few sentences, and is an important part to every entry.

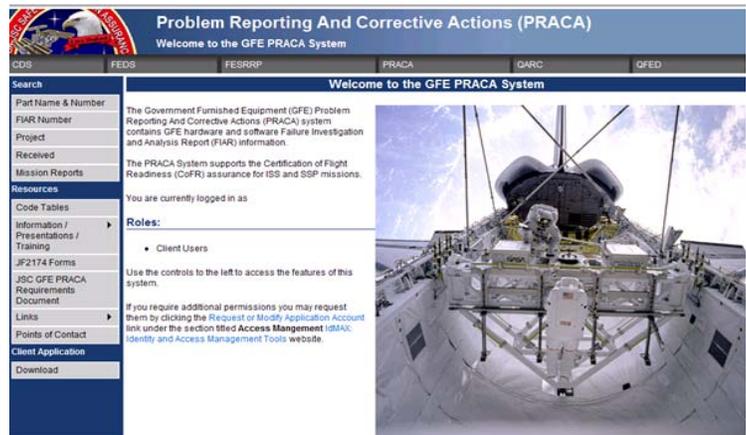


Figure 5. PRACA. Contains transcriptions of FIARs

IV. EVA Tools Expansion

The EMU LLD was originally started for compilation and organization of EMU related FIARs. Upon completion of EMU hardware entries in the Excel database, the website was in development, and work was shifted to transfer entries from the excel version to the web database. The decision was made to improve the EMU LLD and extend the coverage it provides by adding EVA tools and support hardware such as the PGT and the BCM. A total of 606 entries have been added to the database related to EVA tools, taking the total of entries in the EMU LLD from 2360 to 2966. Of these new entries the hardware added includes:

- EMU and EVA Tool Batteries (PGT, REBA, EHIP, SAFER)
- PGT Hardware
- SAFER Hardware
- Wireless Video System
- SPCE (Fluid Pumping Unit, Power Supply Assembly)
- Retractable Equipment Tethers (RET)
- BCM
- Battery Stowage Assembly (BSA)

The format and organization remains the same as with EMU hardware, although a new “Bucket Category” was added to solutions/failures in order to accommodate the hardware: “*Update Software/Firmware*” and “*Unexpected Output*”.

Update Software/Firmware was added to the Solution “Bucket Categories” after analysis of BCM failures showed that corrective action included updating the firmware for a multitude of errors which either had software anomalies or other errors that led to a fault in the software.

Unexpected Output was added to failure “Bucket Categories” to accommodate hardware testing which did not have any failure, but had out of specification readings. Usually the specifications or procedures were changed in order to accommodate the out of spec readings if everything performed nominally (See: Figure 6.).

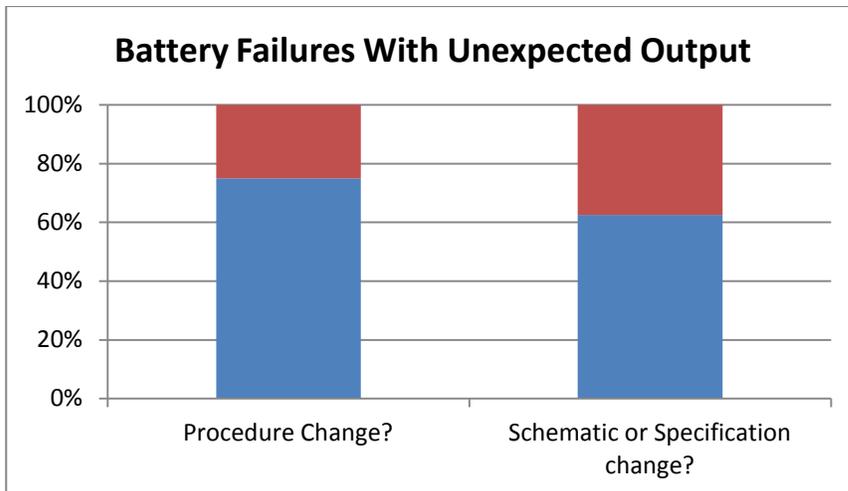


Figure 6. Battery Hardware with Unexpected Output Failure.
Percentage of hardware experiencing unexpected output failure that had the specified corrective action.

V. Conclusion

Since summer of 2009 plenty of work has been done on the EMU LLD, and in its current state, it supports analysis and navigation in the organized Excel interface for the EMU. With the work done this past semester, the EMU LLD now extends coverage to EVA tools and support hardware, for the same purpose in aiding with future

design and current maintenance. With some of the oldest FIARs in the database dating back to the 1970s, the history of EVA tools and the EMU can be carefully analyzed for over three decades of information. The EMU LLD is a valuable tool for development, and will increase in usefulness and accessibility with further development of the website portion in the future.

A. Forward Work

Although much work has been done on the EMU LLD to this point, there is still work to be done for it to reach completion. There are still entries that need to be transferred to the website portion, as only 32% have been moved over from the Excel database. Although, now that hardware FIARs have been entered up to the most recent closures, more focus can be shifted to transferring the entries in the system. As work is being done to convert entries to the correct format for the web database, newer, more recently closed FIARs can be added to the Excel portion. FIARs are added to PRACA periodically as they are closed, and need to be entered in to the EMU LLD for any relevant hardware.

Improvement of the website portion of the database is always a possibility for work. Adding increased functionality such as photographic elements for hardware entries, as well as general aesthetics, and as feedback is taken from the community, the interactive elements of the site can be built upon to make the experience easier for the user. Another possible element, to improve the efficiency of adding new entries, would be a “Direct Entry Addition” system. As of right now, the only way to add entries to the web database is to take data from PRACA to the Excel spreadsheet, from the Excel Spreadsheet to an individual .csv (Comma Separated Value) file for each entry, and finally upload the .csv file to the server containing the web database. The implementation of a feature on the webpage, accessible through administrative permissions, which would allow one to simply fill in fields for text entries, choose from drop down menus for “Bucket Categories,” check off the visual “Bucket Categories,” and directly enter FIARs to the web database, would make the ability to keep the database up to date after completion a much simpler task. The feature could be coded in to the web database through HTML or possibly port the database to another language such as Java or PHP, which allow greater ability, at the cost of being more time consuming to learn.

Acknowledgments

K.M. Matthews would like to say thanks to mentors Scott Cupples and Lori Crocker for the enormous amount of support and guidance given in the development of the EMU LLD, as well as providing an excellent learning experience here at JSC. The previous interns for their work on starting and improving the EMU LLD. K.M. Matthews would also like to recognize Brian Johnson for creating the concept of the EMU LLD. K.M. Matthews would also like to extend thanks to the XA Chief Engineering and Systems Engineering & Integration office for project support and help in development of professional skills. K.M. Matthews would also like to thank Glenn Lutz and the entire XA division for the opportunity to work in and experience the community. And finally, K.M. Matthews would like to thank Undergraduate Student Research Program (USRP) coordinators Diego Rodriguez and Dr. Adams for granting the opportunity to work at JSC and discover the many great things planned in manned spaceflight.

References

- ¹Zygielbaum, Joseph L., “Translation 22: The First Man In Space” *NASA Archives* [online database], URL: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19630043160_1963043160.pdf [cited 09 December 2011].
- ²NSSDC, “Mercury Atlas 6” *National Space Science Data Center* [online archive], URL: <http://nssdc.gsfc.nasa.gov/nmc/masterCatalog.do?sc=1962-003A> [cited 09 December 2011].
- ³Portree, David S. F., Treviño, Robert C., “Walking To Olympus: An EVA Chronology” *NASA Archives* [online archive], URL: <http://history.nasa.gov/monograph7.pdf> [cited 09 December 2011].
- ⁴Hacker, Barton C., Grimwood, James M., “On The Shoulders Of Titans: A History Of Project Gemini” *NASA Archives* [online archive], URL: <http://www.hq.nasa.gov/office/pao/History/SP-4203/ch11-2.htm> [cited 09 December 2011].
- ⁵NASA, “STS-61” *NASA Space Shuttle Launch Archives* [online archive], URL: <http://science.ksc.nasa.gov/shuttle/missions/sts-61/mission-sts-61.html> [cited 09 December 2011].
- ⁶NASA “STS-104” *NASA Space Shuttle Launch Archives* [online archive], URL: <http://science.ksc.nasa.gov/shuttle/missions/sts-104/mission-sts-104.html> [cited 09 December 2011].
- ⁷NASA “STS-6” *NASA Space Shuttle Missions Archive* [online archive], URL: http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-6.html [cited 09 December 2011].