Guidelines for Successful Use and Communication of Instrument Heritage in Early Mission Development with a Focus on Spectrometers

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JPL Student Intern Program

Final Report

August 20, 2012

1.0 INTRODUCTION

Heritage is important for both cost and risk related issues and as such, it is heavily discussed in NASA proposal evaluations. If used and communicated efficiently, heritage can lower both the perception of risk and the associated costs. Definitions of heritage vary between engineering, cost, and scientific communities, but when applied appropriately, heritage provides a benefit to the proposed mission. By making an instrument at least once before, the cost of producing it again can be reduced. The time and effort needed to develop the instrument concept and test the product represent an expense that can be lowered through the use of a previously built and developed instrument. This same thought can be applied when using a flight spare or build-to-print model of the heritage instrument. The lowered perception of risk is a result of the confidence gained in the instrument through successful use in the target environment. This is extremely important in early mission development to the evaluation board. This analysis will use JPL-managed proposals from 2003 to 2011, including Discovery, New Frontiers, and Mars Scout missions. Through the examination of these proposals and their associated debriefs, a set of guidelines have been created for successful use and communication of instrument heritage in early mission development.

2.0 BACKGROUND

There are many variables that can increase the risk perception of an instrument, but in many cases, this increase can then be lowered through the correct use of heritage in the mission proposal. The following are three instances that would increase risk perception and how effective inclusion of heritage can assist in alleviating it. First, when the instrument is a new technology, it does not have the history to show its capabilities in the test environment. There are no past experiences the evaluation board can draw confidence from for the instrument as a whole. While there may not be heritage for the instrument, it may be possible to leverage heritage at the instrument subsystem or component levels if classical design is incorporated. Second, if an instrument is operating in a new environment, changes must be made from the heritage instrument. By having a strong heritage base and following the guidelines provided below, risk perception associated with these changes can decline and result in positive evaluation feedback. Finally, in missions where fulfilling science objectives is heavily dependent on a specific instrument, using successful heritage can create confidence in the instrument and the overall mission.

3.0 METHODS

3.1 Approach:

1. Select target instrument type. (Spectrometers)
2. Analyze mission proposals from 2003 to 2011 that include target instrument.
3. Identify heritage sources by target instrument.
4. Read relevant sections of chosen proposals to determine elements impacting instrument heritage evaluation.

5. Read debriefs, pulling out comments directly related to the target instrument and then comments referencing target instrument heritage.
6. Analyze debrief comments, mission proposals, and analysis products listed below to determine correlations between use and communication of instrument heritage and resulting evaluation.
7. Create guidelines on instrument heritage inclusion.

I chose spectrometers as the target instrument for three reasons. Spectrometers are proposed across a wide range of mission classes by many different providers around the world, there is a great deal of successful heritage, and finally, there are multiple types of spectrometers with varying requirements. This provides diversity while maintaining focus on a small number of instrument types. From 2003 to 2011, 33 spectrometers were identified over 19 mission proposals ranging from Discovery, New Frontiers, and Mars Scout. Mass/neutron, laser, imaging, and gamma ray spectrometers were all included in this selection. From these, 40 instruments spanning 29 past missions were claimed as heritage sources. Four analyses, presented in Table 1 below, organize data and identify patterns in the information. Product 1 made use of the spectrometers' identifying characteristics, while Products 2 and 3 were then created using debrief comments.[1] Product 4 used a combination of the two sources.

3.2 Analysis Products:

TABLE 1: Analysis Products

	Product	Description	Purpose
1	Spectrometer Heritage Table	Table of target instruments and their missions, heritage claims, type of heritage-related debrief comment[2], and any notes related to heritage inclusion in mission proposal	Intermediate document used to organize data and identify patterns in communication of heritage
2	Heritage vs. Instrument Table	Table identifying heritage instruments and heritage evaluation comments	Used to identify heritage instruments that may lead to weaknesses or strengths based on type of instrument.
3	Spectrometer Heritage-Related Strengths and Weaknesses	Two tables of debrief comments related to the heritage of the instrument	Used to identify patterns in evaluation comments
4	NASA Center Heritage Sources	Two tables presenting information on two NASA centers' past heritage sources for their respective spectrometers.	Determine heritage sources these two NASA centers consistently use and its resulting debrief comment.

[1] Proposal debriefs for 10 proposed instruments from 2003 to 2004 were not available.
[2] This includes major strength, minor strength, major weakness, and minor weakness.

The following six tables are examples of the four analysis products. Due to size limitations, the examples do not contain all collected data.

TABLE 2: Subset of Spectrometer Heritage Table

Mission Proposal	Year	Spectrometer	Type of Spectrometer	Provider	Debrief Comment	Heritage Claim	Notes
Competition sensitive information removed.							

Debrief Comment Key:				Neutral: instrument heritage was
++ Major Strength	+ Minor Strength	- Minor Weakness	- - Major Weakness	not commented on in debrief

TABLE 3: Subset of Heritage vs. Instrument Table[3]

	Mission	Instrument	Proposed Instruments: NASA Center 1 Instruments					NASA Center 2 Instrument	Other Institution Instruments	
Heritage Sources	Cassini	Huygen's Probe	X	X	X	X	X			
	Cassini	INMS	X	X			X			
	Contour	Mass Spec.	X	X					X	
	Galileo	GPMS	X	X	X	X	X			
	Giotto	PIA								
	ISS	TGA						X		
	Lunar Prospector	Neutron Spec.							X	
	MSL	SAM			X	X	X			
	Nozomi	Mass Spec.	X	X						
	Odyssey	Neutron Spec.							X	
	PV Orbiter	Mass Spec.	X	X						
	Rosetta	ROSINA								X
	Vega 1 and 2	PUMA 1 and 2								
			N/A	N/A	Instrument suite has strong heritage. **(mnS)**	Most immediate heritage to MSL (not launched), but has heritage to GPMS on Galileo. Limited changes planned. **(MS)**	Has heritage for some subelements, but must make major changes. **(MW)** Galileo's GPMS is mentioned. **(mnS)**	Heritage is overstated. Changes must be made from heritage instrument. Parts have not been flown. **(mnW)**	Instrument suite has strong heritage. **(mnS)**	Flight spare for Rosetta. Already flight qualified. **(MS)**
			N/A	N/A	Concept		Concept	Concept/Proposal	Concept	Concept

Key:

Center 1
Center 2
Other

Strength
Weakness
No debrief available

[3] Example contains only mass spectrometers.

TABLE 4: Spectrometer Heritage-Related Strengths

STRENGTHS			
Proposal	**Year**	**Instrument**	**Comment Highlights**
Competition sensitive information removed.			• Very similar in flight software, flight/ground ops, data management, and archive/data analysis • Strong heritage leads to high resiliency
			• Identical instrument to previous successful missions • Strong heritage leads to reliability and known performance
			• Claims heritage to very successful missions MRO and M^3 • Limited changes to heritage instrument
			• Instrument is a flight spare from Rosetta and as such has had all the development that led to its use on Rosetta • No changes are made from heritage instrument
			• Strong heritage
			• Already been flight qualified as a flight spare for Rosetta • Fully tested
			• Claims heritage to instruments that have not launched yet, but also claims heritage to instruments from past successful missions • Limited and explained changes from heritage instruments
			• Proven technique • Heritage instrument is TRL 8 • Limited and explained changes from heritage instrument • Detailed heritage section *Only weakness was that heritage instrument had not launched yet.
			• Build-to-print from DAWN • Very limited changes
			• Build-to-print from DAWN • Very limited changes

TABLE 5: Spectrometer Heritage-Related Weaknesses

WEAKNESSES			
Proposal	**Year**	**Instrument**	**Comment Highlights**
Competition sensitive information removed.			• Parts don't have flight heritage • Heritage claim is still in development • Significant changes must be made from heritage instrument
			• Heritage isn't described sufficiently
			• Heritage is not clearly stated • From the debrief: "…only information provided is vague reference to Venus Express. No description of how much is heritage, how much reuse, etc."
			• Heritage is not clearly stated
			• Parts don't have flight heritage • Significant changes must be made from heritage instrument
			• Has heritage for some subelements, but must make significant changes from heritage instruments *Minor strength comes from reference to Galileo's GPMS (long history of successful mass spectrometers)
			• Ability not supported by heritage • Significant changes must be made from heritage instrument
			• Not enough heritage • Major changes from heritage instrument must be made

Table 6: NASA Center 1 Heritage Sources

Heritage Mission	Heritage Instrument	Number of proposed spectrometers claiming this mission as heritage	Percentage of proposed spectrometers claiming this heritage (%)	Debrief Comment (if available)	Type of Proposed Spectrometer Claiming this Heritage
Galileo	GPMS	5	100	N/A, N/A, +, ++	Mass
Cassini	Huygen's Probe	5	100	N/A, N/A, +, ++	Mass
Cassini	INMS	3	60	- -	Mass
MSL	SAM	3	60	+, ++, - -	Mass
Contour	MS	2	40	N/A, N/A	Mass
Pioneer Venus Orbiter	MS	2	40	N/A, N/A	Mass
Nozomi	MS	2	40	N/A, N/A	Mass

Number of proposed NASA Center 1 spectrometers: 5	**Debrief Comment Key:**			
	++ Major Strength	+ Minor Strength	- Minor Weakness	- - Major Weakness

Table 7: NASA Center 2 Heritage Sources

Heritage Mission	Heritage Instrument	Number of proposed spectrometers claiming this mission as heritage	Percentage of proposed spectrometers claiming this heritage (%)	Debrief Comment (if available)	Type of Proposed Spectrometer Claiming this Heritage
Gallileo	NIMS	3	30	++	Imaging
Cassini	VIMS	3	30	N/A	Imaging
Mars Express	SPICAM	1	10	N/A	Imaging
Pioneer Venus Orbiter	OIR	1	10	N/A	Imaging
MSL	TLS	1	10	+	Laser
MSL	SAM	1	10	neutral	Laser
ISS	TGA	1	10	- -	Mass
Hyperion	Not specified	2	20	N/A	Imaging
HST	WFC-3	1	10	N/A	Imaging
DI	HRI	1	10	N/A	Imaging
Warfighter	Not specified	1	10	N/A	Imaging
AVIRIS	Not specified	1	10	N/A	Imaging
MRO	CRISM	1	10	++	Imaging
Chandrayaan-1	M3	2	20	++, ++	Imaging

Number of proposed NASA Center 2 spectrometers: 10	**Debrief Comment Key:**			
	++ Major Strength	+ Minor Strength	- Minor Weakness	- - Major Weakness

4.0 RESULTS

Table 2 includes the guidelines to write an effective instrument heritage in mission proposals. It includes two key sections that must be addressed to result in a positive feedback from proposal evaluation teams.

TABLE 2: Guidelines for Using Instrument Heritage Successfully

Heritage Section	Guidelines to Addressing Heritage
How do you use heritage correctly?	1. If applicable to current mission, use a flight spare or build-to-print from a successful mission. 2. If claiming heritage from an instrument that has not launched yet, a. Also use and reference a related successful past mission's instrument. OR b. Explain current development of heritage instrument and its development plan. 3. Minimize changes from heritage instrument. 4. Highlight provider capabilities in proposal if they are leaders of their field.
How can you communicate heritage effectively?	1. Clearly identify all instruments used as heritage for each instrument subsystem. 2. Clearly explain any changes made from heritage instrument. 3. For changes made, identify ways to minimize the differences. 4. If there are instrument subsystems without heritage, thoroughly describe the development plan that will be used. 5. Use strong heritage sources: recognize past instruments and missions that receive positive remarks in proposal debriefs when used as heritage.

5.0 DISCUSSION

The following discussion gives a detailed account of the steps outlined in Table 2 broken up by the two heritage sections.

5.1 How do you use heritage correctly?

There are four steps to using heritage correctly. They were identified using the first three analysis products as well as mission proposals. These steps were written to minimize the perception of risk associated with the instrument. From the evaluations of the mission proposals, major strengths were always given for using a flight spare or build-to-print version of an instrument flown on a past successful mission. This is shown by Instrument A and Instrument B, both flight spares of [Instrument] from the […] mission launched in 2004. By using these premade or previously developed instruments, development

time and cost radically decrease and confidence in the ability of the instrument solidifies. This then lowers the overall perception of risk for the proposed mission.

The second step refers to instruments claiming heritage from one still in development for another mission. There are two options in this case. First, use a successful past mission's instrument as a heritage source as well. This is done well in Mission 1 when explaining its mass spectrometer heritage. While the mission predominantly draws from [Instrument] which had not been flown at the time, it also references [Instrument], a highly successful mass spectrometer.

> "The concept design is similar to the [Instrument] … Many of the subsystems, particularly the electronics, are heavily based on enhancements from this design to the recent development of the [Instrument] that is a significant payload element of the [Mission]." **[1]**

In this case, the past mission was referenced as heritage for the current heritage claim. This technique creates a background for the evaluation team and a stronger credibility for the instrument still in development leading to a lower perception of risk. The second option is to thoroughly explain current development of the heritage instrument and its development plan. This is also done well in Mission 1, but in the explanation of its laser spectrometer heritage. The laser spectrometer also draws heavily from [Instrument].

> "The [Instrument] completed stand-alone functional qualification and environmental testing in 2007. Since then, joint testing at the [Instrument] - level of integration has occurred without revealing any [Instrument] interface problems. The [Instrument] is essentially at TRL-8." **[1]**

As in option one described above, option two creates a stronger credibility for the instrument still in development. This allows the evaluation team to make a better assessment of the current level of development for the proposed instrument and the level of risk it presents.

Step three is to minimize changes made from the heritage instrument. This can be done early in instrument development by selecting a heritage instrument with similar mission conditions. This includes topics such as the target body's environment and the duration of the mission. Variations from the heritage instrument's mission to the currently proposed mission create a possible need for change in design or capability of the instrument. Each change introduces a cost increase and a level of uncertainty in the instrument into the mission proposal. This information came from Product 3 and the proposals.

Finally, step four then says to highlight provider capabilities in the proposal if they are leaders in their field. Not all examined proposals followed this, but in cases such as Mission 2, it resulted in an evaluation strength. The proposal states the following:

> "NASA [Center 1] is providing the Mission 2 MS. [NASA Center 1] has been the leading supplier of low-mass, high-performance, mass spectrometers for planetary applications for the past 35 years." **[2]**

Similar statements are found in Mission 1's discussion of its mass spectrometer heritage and Mission 3's discussion of its mass spectrometer. These comments were responded to in heritage strength comments

with acknowledgement of NASA Center 1's capabilities in mass spectrometers. Data contributing to this step is limited and therefore further analysis must be done to solidify the stated conclusions.

5.2 How can you communicate heritage effectively?

When conveying an instrument's heritage in a mission proposal, there are five steps to take. Step one is to clearly identify all instruments used as heritage for each instrument subsystem. Based on debrief comments, Mission 1 was one of the better proposals at addressing this when describing its laser spectrometer.

> "For heritage purposes, the [laser spectrometer] consists of five components:
> 1. [Laser Spectrometer] [Component] (Figure J.10.3-5): Derived from [Instrument]. Partial Heritage.
> 2. [Lasers]: [Laser 1] is derived from [Mission] Modular replacement of [Component] with [Component]. Addition of a third laser channel, also a [Component]. Partial heritage.
> 3. Electronics: Derived from [Instrument]. Partial heritage.
> 4. Software: Derived from [Instrument]. Partial heritage.
> 5. [Component]: New design using components from [Instrument], but repackaged. Partial heritage." **[1]**

The proposal goes on to describe each component in more detail, explaining each change made from the stated heritage and why. This level of detail is cited as a strength in the mission debrief. In comparison, the following example is taken from Mission 4.

> "All [imaging spectrometer] subsystems (opto-mechanics, electronics) have been developed and used in previous planetary exploration programs such as [Instrument], [Instrument], and [Instrument]." **[4]**

This is the only mention of these heritage instruments in the proposal. There is no mention of what was taken from each instrument or how strong of a heritage it had to each. The resulting debrief comment was, "The [imaging spectrometer] spectrograph performance requirements, heritage… are not provided with sufficient detail or clarity to provide confidence that it can meet its scientific goals." **[5]** To receive strengths in mission evaluations, it is necessary to fully describe not only the instrument heritage, but how strong of a heritage it is and what instrument subsystem is claiming that heritage.

Step two is to clearly explain any changes made from the heritage instrument. Again, based on the debriefs, Mission 1 was the best of the examined proposals at this step. This information is needed to determine how strong of a heritage the instrument has to its heritage claim. As in step one, this is important to receive strengths from the evaluation team. As stated previously, each change increases development cost as well as the perception of risk associated with the instrument. Related to step two, step three is then to identify ways to mitigate any changes needed from the heritage instrument. From the proposals, two possible options include using a supplier that has been successful in the past missions or, if using a different subsystem than the heritage instrument, choose one that has been successfully flown before.

Step four states that if there are instrument subsystems without heritage, thoroughly describe the development plan that will be used to make the subsystem flight ready. A large increase in the perception of risk can occur without this detailed description. Each subsystem is vital to instrument functionality. Without a reason to have confidence in the individual subsystems, the evaluation team cannot be confident in the instrument as a whole.

Finally, step five states to recognize past instruments and missions that receive positive remarks in proposal debriefs when used as heritage. This step would be used in early instrument development when determining heritage instruments. The following past missions have all received consistent positive remarks or have been specifically mentioned as strong heritage in the evaluations.

1. [Instrument]
2. [Instrument]
3. [Instrument]
4. [Instrument]
5. [Instrument]

From this list, [Instrument], [Instrument], and [Instrument] have been mentioned directly in the debriefs. The following example is from the evaluation of the Mission 3's mass spectrometer.

> "[The mass spectrometer] leverages its design from a long history of successful mass spectrometers that includes the [Instrument], which has flown." **[3]**

This information came from Products 2 and 3 as well as the available debriefs. The inclusion of these missions in proposal debriefs suggest a common recognition of success and reliability by the evaluation team.

5.3 Two NASA Centers' History of Instrument Heritage Use

To understand how instrument heritage is presently being discussed in mission proposals and responded to in evaluations, it is important to look at the individual instruments, their heritage claims, and debrief comments. This information was laid out in Product 2, separated by type of instrument. The two NASA centers were chosen as a focus due to their leadership in the fields of mass and imaging spectrometers respectively.

Competition sensitive information was removed.

5.4 Future Work

Future work may include:

1. Examine debrief comments for other types of instruments to verify the proposed guidelines.
2. Apply the analysis products above to mission proposals' spacecraft heritage as well to create a complete set of guidelines for early mission development.
3. Compare and contrast guidelines from #2 to guidelines above to determine consistency in heritage evaluation in mission proposals.

While the analyzed spectrometers relate to a variety of instruments due to the varying requirements of the four types, a wider analysis of instrument heritage in the selected years and mission classes should be performed to verify the proposed guidelines. The following step would then be to apply the products above to spacecraft heritage in mission proposals to create a second set of guidelines. To determine consistency in heritage evaluation over mission proposals as a whole, a compare-contrast analysis can be done between these guidelines and the guidelines above.

6.0 CONCLUSIONS

The use of instrument heritage plays a key role in reducing the perception of risk in early mission development. Introducing instrument heritage into a mission proposal gives the instrument a sense of credibility that results from previous success in its target location. This analysis focused on the creation of a set of guidelines on effective use and communication of instrument heritage in mission proposals. By focusing on what heritage means, how to use heritage correctly, and how to then communicate it effectively, these guidelines can be applied simply and result in a thorough description of instrument heritage. The goal of this analysis is to provide a method that can be used to receive positive evaluation feedback in regards to instrument heritage.

7.0 Acknowledgements

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the JPL Student Intern Program and the National Aeronautics and Space Administration. I would like to thank Dr. Lynne Cooper for her guidance and constant supply of snacks. I would also like to thank Jan Ludwinski, Brent Sherwood, and Randii Wessen for their support. Finally, I would like to thank the Brick House for their endless supply of help and encouragement.

8.0 Bibliography

Competition sensitive information was removed.