A 20 YEAR LIFECYCLE STUDY FOR LAUNCH FACILITIES AT THE KENNEDY SPACE CENTER

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ABSTRACT

The lifecycle cost analysis was based on corrosion costs for the Kennedy Space Center's Launch Complexes and Mobile Launch Platforms. The first step in the study involved identifying the relevant assets that would be included. Secondly, the identification and collection of the corrosion control cost data for the selected assets was completed. Corrosion control costs were separated into four categories. The sources of cost included the NASA labor for civil servant personnel directly involved in overseeing and managing corrosion control of the assets, United Space Alliance (USA) contractual requirements for performing planned corrosion control tasks, USA performance of unplanned corrosion control tasks, and Testing and Development. Corrosion control operations performed under USA contractual requirements were the most significant contributors to the total cost of corrosion. The operations include the inspection of the pad, routine maintenance of the pad, medium and large scale blasting and repainting activities, and the repair and replacement of structural metal elements. Cost data was collected from the years between 2001 and 2007. These costs were then extrapolated to future years to calculate the 20 year lifecycle costs.

KEY WORDS

Lifecycle, Cost, Corrosion, NASA, Kennedy Space Center, Launch Pad, Launch Complex, Mobile Launch Platform

INTRODUCTION

The natural marine environment at the Kennedy Space Center (KSC) has been documented by the American Society for Metals (ASM) as having the highest corrosion rate of any site in the continental United States.[1] As a result, launch structures and ground support equipment at KSC degrade faster than assets at other locations. With the introduction of the Space Shuttle in 1981, the already highly corrosive natural conditions at the launch pads were rendered even more severe by the acidic exhaust from the solid rocket boosters. As a consequence, corrosion-related costs are significant for all launch structures.

The objective of this study was to perform a lifecycle cost analysis to determine the baseline operational lifecycle costs, and operational manpower inspection requirements for corrosion control of NASA's Kennedy Space Center (KSC), Launch Complex 39 facilities and the Mobile Launch Platforms using conventional corrosion control coating systems at KSC.

ASSETS INVESTIGATED IN THE LIFECYCLE ANALYSIS

KSC launch operations utilize seven major structures that include two Launch Complexes, three MLPs and two Mobile Crawlers. Collectively, these assets are comprised of 5,443,696 ft^2 of structural steel.[2] While the mobile crawlers are not a part of the lifecycle analysis, the sheer magnitude of the structural steel gives a clear indication of the corrosion issues at KSC. This lifecycle cost analysis only looks at the corrosion costs associated with launch complexes 39A and B and the Mobile Launch Platforms.

Launch Complex 39 – Pads A & B

Two complexes support mobile launch operations and are available for Space Shuttle launches. LC 39A and LC 39B are *"sisters"* of each other, and share similar characteristics. For the purpose of this lifecycle analysis, a significant portion of the costs are delineated by the different sections of the launch pads. These sections are the:[3]

        a.   Fixed Service Structure (FSS)
        b.   Rotating Service Structure (RSS)
        c.   Perimeter
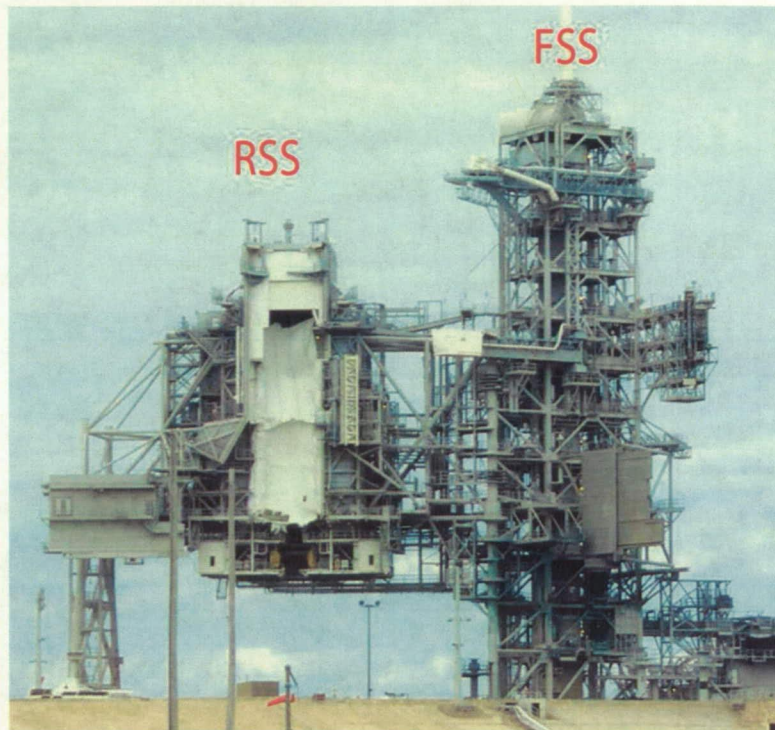   d.   Pad Structures

Figure 1 - KSC Launch Complex

The Fixed Service Structures (FSSs) and MLPs were originally designed for a 20 year lifespan with the liquid propellants from the Apollo era vehicles. Even after 40 years, the structures remain in use with the Space Shuttle and its acidic exhaust from the solid rocket boosters.[4]

The Rotating Service Structure (RSS) provides a means to install and service Space Shuttle payloads while at the pad. This structure also supports servicing operations on the Space Shuttle that can't be performed from the FSS.

The perimeter of the launch pads is the area inside the fence, but below the pad surface. It includes the Liquid Oxygen (LOX) and Liquid Hydrogen (LH2) storage tanks, as well as pipes, tanks and small buildings. The LOX and LH2 tanks provide liquid oxygen and liquid hydrogen to the Space Shuttle's external tank prior to launch.

Mobile Launch Platforms (MLP-1, MLP-2 and MLP-3)

Three mobile launch platforms are available to transport the Space Shuttle from the VAB to the launch pads. The MLPs are transported by the Mobile Crawlers. Once the Space Shuttle is affixed to the MLP in the Vehicle Assembly Building, it is transported to the launch pad where the MLP remains in place throughout launch.

Figure 2 - MLP Transporting the Space Shuttle

Each mobile launch platform is approximately 25 ft tall, 160 ft. long and 135 feet wide. Alone, each MLP weighs approximately 9.25 million pounds. Loaded with the Space Shuttle, the combined weight is approximately 12.02 million pounds.[5]

CORROSION AT THE KENNEDY SPACE CENTER

The launch facilities at KSC are approximately 1000 feet from the Atlantic Ocean. The seacoast marine location is extremely corrosive to structural steel. In fact, the location is documented as one of the most corrosive environments in the world. Table 1 shows the corrosion rates for the KSC beach corrosion test site.

Table 1 - Corrosion Rates of Carbon Steel Calibrating Specimens at Various Locations [1]

Location	Type of Environment	μm/yr	Corrosion rate mils/yr
Esquimalt, Vancouver Island, BC, Canada	Rural marine	13	0.5
Pittsburgh, PA	Industrial	30	1.2
Cleveland, OH	Industrial	38	1.5
Limon Bay, Panama	Tropical marine	61	2.4
East Chicago, IL	Industrial	84	3.3
Brazos River, TX	Industrial marine	94	3.7
Daytona Beach, FL	Marine	295	11.6
Pont Reyes, CA	Marine	500	19.7
Kure Beach, NC (24 m from ocean)	Marine	533	21.0
Galeta Point Beach, Panama	Marine	686	27.0
Kennedy Space Center, FL (beach)	**Marine**	**1070**	**42.0**

The corrosion rates in the table show the aggressiveness of the location at KSC. The corrosion problems at the launch pads are made worse by the rocket blast and acidic exhaust from the solid rocket boosters. The acidic environment makes many coatings and alloys that would normally work in marine conditions ineffective. As a consequence, corrosion control is a high priority issue at KSC.

KSC's Corrosion Technology Laboratory has conducted research in the field of corrosion since 1968. In 1969, a testing program was initiated to evaluate coatings for the long term protection of carbon steel exposed to a sea coast environment. As a result of this corrosion program, a surface preparation and coating standard (KSC-STD-C-0001) was developed.

Testing of protective coatings for carbon steel, stainless steel, and aluminum has been an ongoing process for many years. The original standard has been continually revised throughout the years, and is currently denoted as NASA-STD-5008, *Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities and Ground Support Equipment.* A revision of NASA-STD-5008 is currently in process.

In 1981, the Space Shuttle launch system was introduced into the manned space program. This launch system utilized twin solid rocket boosters, which produced hydrochloric acid and small particles of alumina in the exhaust. Wherever a cloud of this exhaust settled, unprotected zinc coatings in use at the time provided little protection to the underlying substrate. To counter these effects, new coating systems were developed and implemented including the introduction of an inorganic zinc topcoat.

NASA-STD-5008 provides guidance on the coatings to be used for corrosion control at NASA. The standard includes a qualified products list (QPL) and the testing protocols that must be passed for a new coating to be incorporated into the QPL. Corrosion control operations personnel consult the standard and QPL to determine the appropriate coating systems and application method based on the metal alloy being coated and the location.

KSC's Applied Technology Directorate routinely tests coating systems for the NASA-KSC-5008 standard. Coatings that pass the criteria of this standard are subsequently added to the NASA STD-5008 Qualified Products List (QPL). As prescribed by NASA-STD-5008, the launch pad structure is divided into different zones of exposure that define coating system requirements. The zones are delineated with regard to direct/indirect rocket engine exhaust impingement, acid deposition, and elevated temperature. A depiction of these zones of exposure for the launch pad is shown in Figure 3.
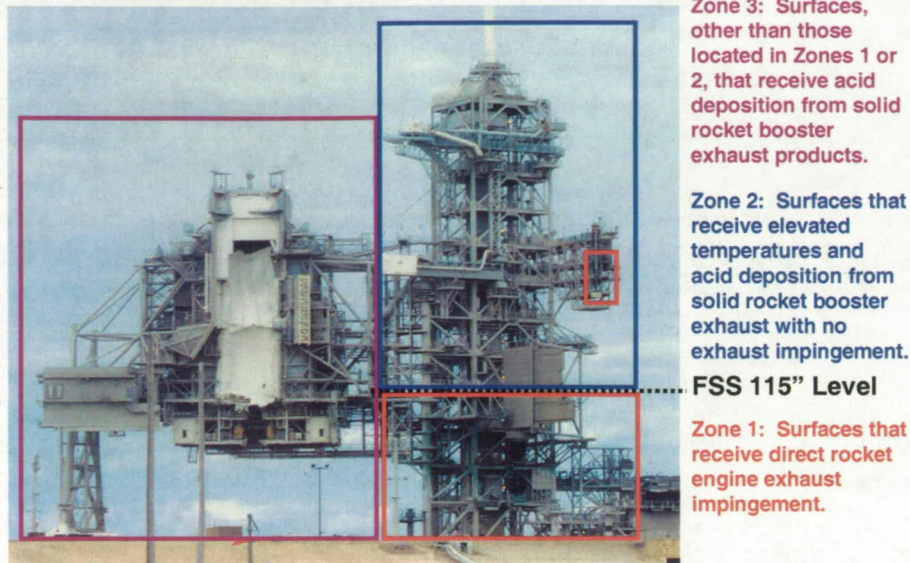
Zone 3: Surfaces, other than those located in Zones 1 or 2, that receive acid deposition from solid rocket booster exhaust products.

Zone 2: Surfaces that receive elevated temperatures and acid deposition from solid rocket booster exhaust with no exhaust impingement.

FSS 115" Level

Zone 1: Surfaces that receive direct rocket engine exhaust impingement.

Figure 3 - Launch Complex Zones of Exposure

Until the early 1990s, a three coat polyurethane coating system was predominantly used at the launch pads and on the MLPs. The lifespan of this system was approximately three years in duration. Today, inorganic zinc is the predominant coating used at the launch complexes and on Ground Support Equipment.

Above the 100-110 ft level, the zinc rich primer is coated with an inorganic topcoat. The inorganic topcoat is designed to provide a chemically resistive barrier to the acidic exhaust from the solid rocket boosters. In high heat areas (below the 95 ft level), a silicone ablative topcoat is used on top of the inorganic zinc primer. The silicone ablative coating is also used as a sealer in damp areas.

When a coating fails, there are a number of safety issues and repairs that may arise including:

    a. metal replacement
    b. the failure of an assembly
    c. the liberation of Foreign Objects and Debris (FOD).

Metal replacement is the most expensive repair and occurs when an element of the structure has corroded beyond repair. This can include structural members that corrode either completely, or to the point where they can no longer provide structural support. Early detection of corrosion can reduce this type of repair.[6] By decreasing the quantity of metal that is replaced through the early detection of corrosion, a significant savings for labor and materials will be realized. An assembly can fail when, for example, a bolt breaks and the structure is compromised or FOD is created. FOD can also be generated by large rust flakes, called pancake rust.

Asset Inspection

In 2000, a software inspection and database program, BaseCoat, was integrated into the KSC corrosion control inspection program.[7] The computerized database is useful since it documents corrosion at the launch pads, and allows the inspector to view the progression of corrosion from one year to the next.

BaseCoat is a maintenance management software tool designed specifically for paint and protective coatings. This program is extensively used for coating repair and maintenance at the launch pads at KSC. BaseCoat can be used for:[8]

- organizing existing current asset data,
- performing and analyzing condition surveys,
- prioritizing work requirements,
- estimating coatings maintenance costs,
- forecasting budget requirements.

Routine inspection of the launch pads and MLPs is required to recognize corrosion prior to the need to replace metal. Currently, labor for one full time inspector per year is allocated for the inspection of the launch pads and MLPs. The inspector will survey the pad and identify areas that need immediate repair, and note areas that might need repair in the future. The amount of repair to be done is ultimately decided by the available budget, time constraints and whether the repair will effect other operations of other systems.

The Three "Typical" Corrosion Control Activities at KSC

There are three basic corrosion control activities that are performed at KSC. The following is a general description of the maintenance and refurbishment procedures that occur during a corrosion control effort at LC-39A, LC-39B, MLP-1, MLP-2, or MLP-3. The repairs to be done at the pad are identified by the corrosion inspector with the aid of the BaseCoat program. Not all of the necessary repairs are performed due to budget constraints, time constraints or effects to other systems. Some systems, including powered systems at the launch complexes are not repaired when needed because the corrosion inspector and work crew do not have authority to work on all systems. As a consequence, the owner of the specific system must provide approval and funding to work on their system.

Small Scale, Spot Corrosion Effort

A small scale, spot corrosion effort is one where the overall coating is in fair condition and may contain spots of pancake rust (FOD concern) within the defined area. During this type of effort, the corroded areas are cleaned with hand/power tools, which may include needle guns or abrasive wheels. Once the rusted areas are cleaned to bare steel, the region is wiped with a solvent to assure that contaminants are removed and

the new coating will adhere to the surface properly. The newly prepared areas are then usually coated with an inorganic zinc if the surface preparation has been sufficient or with a three coat system of aluminum mastic, epoxy coating and polyurethane topcoat (or other coating system depending upon the need, substrate or zone).

Medium Scale Spot Corrosion Effort with Steel Replacement

In an area that has numerous spots of corrosion and the possibility of steel replacement exists, the decision may be made to set up equipment, blast the entire area and repaint. This effort is much more expensive than the prior scenario, and takes considerable effort to set up. Blast equipment such as a media hopper, blast pot, air compressor, hoses and lines are required. This type of effort usually involves erecting containment around the area, and protecting sensitive items during the blasting operations. Once the support equipment, containment and protection are set up, the area is pressured washed to rid the surface of contaminates prior to blasting. This equipment must be set up wherever it is needed on the pad, including the higher levels and those not directly accessible by the elevator. When the area is clean and dry, blasting proceeds until all areas are blasted to a near white finish per the NASA and NACE (National Association of Corrosion Engineers) standards. When blasting is complete, the steel is inspected to ensure that it still has the minimum required thickness (some of these areas may be identified up front and replaced prior to blasting). Items which require replacement are fabricated and blasted prior to installation. The entire area is then primed with inorganic zinc, and top coated with an inorganic topcoat. Depending upon the substrate and zone, other coating systems may be used. Once the coating is applied, all equipment, containment, and protective wrappings are removed and the site is cleaned. This type of effort typically occurs at 5 year plus intervals.

Complete Blast and Paint Effort

This effort is similar to the medium scale effort, with an entire substructure being refurbished instead of a level of the structure or section of the MLP. An example of this includes the blast and repaint of significant portions of the RSS and FSS on Pad B during FY 04 and FY 05, and Pad A in FY 05 and FY 06.

This type of effort usually occurs every 10 years, and requires a downtime period of six months or more. Setup for this type of operation can be significant. Wrapping of sensitive components and erecting the necessary containment required over a month to complete.

TWENTY YEAR LIFECYCLE ANALYSIS

The lifecycle assessment provides an approach and method for identifying the costs associated with the lifecycles of materials and services. NACE International provides an excellent reference for the lifecycle analysis of individual facility components.[9] For example, the question could be asked as to whether a stainless steel pipe might be a better choice than a carbon steel pipe. The NACE standard would be useful in answering this question.

The lifecycle cost analysis (LCCA) is an economic analysis tool that is used to compare the relative merit of competing project alternatives.[10] The basic steps for the lifecycle analysis are similar in all cases. An excellent summary and additional resource for the process can be found in the NAVFAC Economic Analysis Handbook.[11]

Determining Costs

When the study was initiated, the factors that influence cost were identified. These sources make up the major areas of funding for corrosion control at LC39A, LC 39B, MLP-1, MLP-2 and MLP-3.

Four components that influence corrosion control costs were delineated prior to the lifecycle analysis. They were labeled as:

1. NASA
2. USA Contracts
3. USA Standing Ground Operations
4. Testing and Development

The NASA component refers to the labor costs associated with the direct oversight and management of corrosion control tasks by civil servant personnel.

The second component (USA Contracts) pertains to contractual requirements for performing planned corrosion control tasks by USA and USA subcontractors. This component is by far the largest of the four. Most of the funding in this section is appropriated for tasks exceeding 240 hours of labor[12]. Typically, this type of work is initially estimated by USA personnel, and then submitted for bid to subcontractors. While the work is performed, USA personnel record and tabulate the cost in a USA developed database.

The third component refers to performance of mostly unplanned corrosion control tasks (USA Standing Ground Operations). This avenue is used to make inexpensive and relatively quick corrosion repairs when required. Generally, these repairs require less than 240 hours of labor.

Testing and Development costs are associated with the evaluation of coatings and materials at the launch pads.

Historic Coating Costs

Historic coating costs from 2001 to 2007 are tabulated and presented in Table 2. These costs are broken down between the four cost components (USA Contractual, USA Standing Ground Operations, NASA Corrosion Control and Oversight, and Testing and Evaluation).

USA Contractual Costs

The costs were initially segregated by the launch pads and MLPs. The launch pads were further delineated by FSS, Perimeter, Pad Surface and RSS. Where possible, costs were broken down by sub-asset (FSS, RSS, perimeter and pad surface. In total, USA contract cost figures are comprised of labor and materials in the direct performance of corrosion control work, asset inspections, miscellaneous expenses and additional contracts outside of the USA corrosion budget.

Direct corrosion control work and inspection costs were broken down by asset and sub-asset (FSS, RSS, Perimeter and Pad Surface). Inspection costs were segregated by launch pads and MLPs. Routine inspections of the launch pads and MLPs are required to recognize corrosion prior to needing to replace metal. These inspections were performed by a NACE qualified engineer and a NACE qualified technician. On average, the inspectors spent approximately 2000 hours each year inspecting the assets for signs of corrosion, and documented the results in the BaseCoat database.

Miscellaneous costs, while not trivial, represent extraneous expenses that result from the required insurance bonds, mobilization and other contract expenses. Miscellaneous expenses were not available for FY 2001-2003. As a consequence, these figures were based on the percentage of miscellaneous cost as a function of project size for the subsequent years.

Miscellaneous costs were calculated at between 8% and 15% for the launch pads. The average of the percentage of costs that were defined as miscellaneous for LC 39A and 39B from 2003 - 2007 was 11%. Consequently, 11% was used to estimate the miscellaneous costs for FY 2001 through FY 2003 for LC 39A and LC 39B.

The percentage of miscellaneous costs (as a function of corrosion costs) for MLP-1, MLP-2 and MLP-3 for FY2004-FY2007 ranged from 5% to 15%. The average

percentage for MLP-1, MLP-2 and MLP-3 was 8%, 13% and 11%, respectively. Consequently, the estimation of miscellaneous costs for years when contractual work was performed on the MLPs was estimated at 11%.

Additional projects costs were incurred during FY 2004-2006. These costs were high dollar repair and maintenance efforts not originally included as a part of the corrosion control budget. Unfortunately, while it was determined that the projects were related to the FSS and RSS, a delineation of the subsections of the assets (FSS, RSS etc.) was not available.

USA labor costs for the inspections per asset were provided for FY 2003 through 2007. FY2001 and FY 2002 values were calculated based upon a linear extrapolation of the subsequent yearly labor costs and rates. The total costs were recorded by asset, and are presented in the final row for each asset.

USA corrosion control management and oversight costs were not included in the project costs. To account for these personnel, an estimate of the loaded rate for each employee was multiplied by the number of productive hours for the year. The summed totals are listed under "USA Corrosion Control Management & Oversight" in Table 2.

USA Standing Ground Operations

USA Standing Ground Operations are small scale efforts aimed at providing immediate support when required. Typically, standing ground operations provide less than 240 hours of effort per project.

USA does not keep segregated records for Standing Ground Operations. As a consequence, USA personnel estimated the cost of Standing Ground Operations as a 2% factor of the annual corrosion budget for the launch pads and MLPs.[13] The total cost for USA Standing Ground Operations by year are listed in Table 2.

NASA Corrosion Control and Oversight

NASA Corrosion Control and Oversight Costs were not included in the project costs. To account for NASA personnel, an estimate of the loaded rate for each employee was multiplied by the number of productive hours for the year. The summed totals are listed under "NASA Corrosion Control & Oversight" in Table 2.

Testing and Development

The Corrosion Technology Laboratory at the NASA Kennedy Space Center is a network of capabilities – people, equipment, and facilities that provide technical innovations and engineering services in all areas of corrosion for NASA and external customers.

Table 2 – Tabulated Corrosion Cost by Year

All Values in Thousands		2001	2002	2003	2004	2005	2006	2007	Total Dollars
USA Contractual Costs									
Pad A	FSS	$118	$382	$1,065	$287	$511	$514	$2,495	$5,371
	Perimeter	$0	$1	$0	$18	$173	$590	$197	$979
	Pad Surface	$45	$479	$23	$10	$817	$3,693	$949	$6,016
	RSS	$323	$350	$907	$154	$455	$710	$543	$3,442
	Misc.	$53	$133	$219	$40	$303	$558	$314	$1,621
	Additional Contracts	$0	$0	$0	$0	$6,632	$3,899	$0	$10,531
	Inspections	$48	$50	$51	$53	$54	$56	$58	$370
	Total	$588	$1,395	$2,266	$561	$8,946	$10,020	$4,555	$28,331
Pad B	FSS	$353	$145	$839	$372	$335	$138	$61	$2,244
	Perimeter	$17	$2	$410	$11	$147	$255	$644	$1,486
	Pad Surface	$193	$391	$476	$97	$382	$372	$309	$2,220
	RSS	$82	$411	$41	$94	$85	$942	$357	$2,011
	Misc.	$71	$104	$194	$50	$146	$175	$210	$950
	Additional Contracts	$0	$0	$0	$4,934	$4,934	$0	$0	$9,869
	Inspections	$48	$50	$51	$53	$54	$56	$58	$370
	Total	$764	$1,103	$2,011	$5,612	$6,084	$1,937	$1,638	$19,150
MLP-1		$0	$0	$263	$2,178	$0	$32	$86	$2,559
	Misc.	$0	$0	$29	$187	$0	$3	$4	$223
	Inspections	$12	$13	$13	$13	$14	$14	$15	$95
	Total	$12	$13	$305	$2,378	$14	$50	$104	$2,876
MLP-2		$0	$0	$1,474	$2,843	$288	$0	$82	$4,687
	Misc.	$0	$0	$162	$231	$47	$0	$13	$453
	Inspections	$12	$13	$13	$13	$14	$14	$15	$95
	Total	$12	$13	$1,649	$3,087	$349	$14	$110	$5,235
MLP-3		$0	$117	$0	$1,182	$519	$0	$251	$2,070
	Misc.	$0	$13	$0	$97	$81	$0	$26	$218
	Inspections	$12	$13	$13	$13	$14	$14	$15	$95
	Total	$12	$143	$13	$1,293	$614	$14	$292	$2,382
USA Corrosion Control Management & Oversight		$0.6	$0.6	$0.6	$0.6	$0.6	$0.7	$0.7	$751
Total		$1,389	$2,667	$6,245	$12,932	$16,007	$12,037	$6,700	$58,725
USA Standing Ground Operations									
Total		$28	$53	$125	$160	$89	$163	$134	$751
NASA Corrosion Control and Oversight									
Total		$210	$216	$223	$230	$237	$244	$252	$1,611
Testing and Evaluation									
Total		$0	$33	$106	$89	$219	$265	$267	$980
Grand Total									
Grand Total		$1,627	$2,969	$6,699	$13,411	$16,551	$12,710	$7,353	$62,067

Corrosion costs for testing and development were only tabulated for the Launch Complexes and MLPs.

Tabulated Corrosion Costs by Year

Analysis of the tabulated cost by year is informative since it highlights major events or functions that had a pronounced influence on corrosion related costs.

In 2000, the BaseCoat inspection software was introduced into the KSC Corrosion Control Program. This program is utilized by two NACE coating inspectors. By collecting area measurement, condition photographs, dry film thickness measurements and performing coating evaluations, corrosion personnel are able to:

- Estimate the cost of blasting and painting operations
- Estimate the time needed for blasting and painting operations
- Compare facilities on the basis of overall corrosion
- Compare photos of the same location over many years to see the progression of corrosion

According to USA personnel, the BaseCoat system was able to provide documented evidence of corrosion at the launch pads, and as a result, is partly responsible for the increased funding for corrosion control efforts.

Prior to 2001, it was generally accepted that the launch structures and MLPs were operating almost solely according to reactive maintenance procedures. Consequently, little preventative maintenance was performed on the structures since the Shuttle was scheduled to be replaced.

On February 1, 2003, the Shuttle Columbia was lost over Texas while preparing to land at KSC. The loss resulted in an extended period of time when corrosion control efforts could be implemented and evaluations could be conducted. This resulted in increased corrosion control costs during the 2003-2005 timeframe.

One effort involved corrosion repairs on the MLPs during 2004. During the Columbia related "downtime", it was decided to replace the blast/heat shield on the MLPs. During the replacement, it was discovered that major portions of the underlying structural steel had deteriorated from corrosion. Had there been a method to inspect the area for corrosion, it is more than likely that the extensive damage could have been remediated. Instead, the replacement of large sections of structural steel was required.
Additional corrosion control expenses were incurred during FY 2004, and resulted from the abnormally high number of hurricanes that hit KSC.

Lifecycle costs for future years are given in present value dollars. This process is performed by adjusting the value of a dollar for inflation (or other factors) using a discount rate. The discount rate that was used for the lifecycle calculations was

obtained from OMB Circular A-94, Appendix C, January, 2008.[14] The real discount rate of 2.8% was used for all lifecycle calculations.

The cost of a product or service can change due to other factors besides inflation. The increase in these costs is known as the escalation rate. The escalation rate was obtained from the *"Kennedy Space Center Facility Construction and GSE Cost Index"* Report. According to the report, a *"7.7% escalation will still provide a 70% probability that we will not overrun escalation"*.[15] Consequently, it is expected that costs will increase by 7.7%, and this escalation factor was used for all lifecycle calculations.

The initial costs for the assets were based upon the average costs from FY 2001-2007. These values take into account the years where little corrosion control was performed (such as FY 2001), and other years when large scale corrosion control efforts were in full swing (FY 2004 – FY 2006).

Lifecycle Calculations

The lifecycle analysis was performed to determine the initial and future costs and benefits associated with corrosion at KSC. An inherent problem in any kind of evaluation is the difficulty in making value considerations over different periods of time. To compensate for this problem, calculations are used to account for increased yearly costs with an escalation factor. The escalation factor takes into account reduced purchasing power that is a factor of, but not limited to; inflation, material costs, distribution issues and employment. In essence, the escalation rate represents the increased cost of performing work from one year to the next.

All future year costs were based upon costs for maintenance and refurbishment of the assets, and were adjusted to future year values with the escalation factor. The percent increase in the maintenance and refurbishment costs were calculated as follows:

Equation 1 - Escalation Factor[9]

$$E(T) = (1+R)^T - 1$$

E(T) = Escalation Factor
R = Annual Escalation Rate
T = Time in Years

The percent increase for each year was adjusted using a 7.7% escalation factor. Once adjusted for the escalation of costs, the maintenance and refurbishment figures were summed to produce a yearly total.

The escalation factor was incorporated into each asset to anticipate the increased yearly costs through the 20 year lifecycle analysis. As an example, the cost of labor

and materials for MLP-1 will clearly be more expensive in 2028 than they are now. Consequently, the yearly cost was escalated for successive yearly costs using a 7.7% escalation rate and equation 1. The escalation factor was applied to each future year cost. These values were summed to produce a total yearly cost for future years.

Costs and benefits also cannot be compared without accounting for the opportunity value of time. This is known as discounting. Discounting is best understood as the reverse of compound interest. It produces a present value of money from a value in the future.

For the lifecycle analysis, the discount factor took into account, and adjusted the summed yearly costs for the assets based upon an investor's time value of money. The discount factor was calculated as follows:

Equation 2 - Discount Factor[9]

$$P(T) = 1/(1+R)^T$$

P(T) = Discount Factor
R = Real Discount Rate
T = Time in Years

The real discount rate of 2.8% was obtained from OMB Circular A-94, Appendix C, January 2008.[14]

To account for the time value of money, a "*Real Discount Rate*" of 2.8% was factored into equation 2 to produce a yearly discount factor. This premise takes into account the investors desire to receive a fixed payment today, rather than at some future time. Simply put, an investor would prefer to place money in an interest bearing investment. Therefore, the future value of money is decreased since the investor could have placed the funds in an investment bearing vehicle instead. The product of the total yearly cost and the discount factor produced the present value cost for future work by year. The yearly present value therefore takes into account the escalated costs for labor and material, as well as the investors desire to earn money on the investment instead of sinking it into an asset. Factoring the discount rate into this value results in the present value of money.

Once the maintenance and refurbishment costs were adjusted for escalation and the time value of money to calculate the present value for each year, they were summed to obtain a cumulative net present value.

Lifecycle Cost Analysis

The lifecycle calculations were used to determine future yearly corrosion costs.

Table 3 – Lifecycle Calculations for Corrosion Remediation at the KSC Launch Pads and MLPs

Lifecycle Corrosion Analysis for the KSC Launch Pads and MLPs (All Values in Thousands)

Year	LC 39A*	LC 39B*	MLP-1*	MLP-2*	MLP-3*	Other*	Total*	Discount Factor†	Present Value	CUM NPV
2008	$4,722	$3,192	$479	$872	$397	$370	$10,032	1.00	$10,032	$10,032
2009	$5,086	$3,438	$516	$939	$428	$398	$10,804	0.97	$10,510	$20,542
2010	$5,477	$3,702	$556	$1,011	$460	$429	$11,636	0.95	$11,011	$31,553
2011	$5,899	$3,988	$598	$1,089	$496	$462	$12,532	0.92	$11,536	$43,089
2012	$6,353	$4,295	$644	$1,173	$534	$498	$13,497	0.90	$12,086	$55,175
2013	$6,842	$4,625	$694	$1,264	$575	$536	$14,537	0.87	$12,662	$67,837
2014	$7,369	$4,981	$748	$1,361	$620	$577	$15,656	0.85	$13,265	$81,103
2015	$7,937	$5,365	$805	$1,466	$667	$622	$16,862	0.82	$13,898	$95,000
2016	$8,548	$5,778	$867	$1,578	$719	$670	$18,160	0.80	$14,560	$109,561
2017	$9,206	$6,223	$934	$1,700	$774	$721	$19,558	0.78	$15,254	$124,815
2018	$9,915	$6,702	$1,006	$1,831	$834	$777	$21,064	0.76	$15,981	$140,796
2019	$10,678	$7,218	$1,083	$1,972	$898	$837	$22,686	0.74	$16,743	$157,539
2020	$11,500	$7,774	$1,167	$2,124	$967	$901	$24,433	0.72	$17,541	$175,081
2021	$12,386	$8,373	$1,256	$2,287	$1,041	$971	$26,314	0.70	$18,377	$193,458
2022	$13,340	$9,017	$1,353	$2,463	$1,122	$1,045	$28,340	0.68	$19,253	$212,711
2023	$14,367	$9,712	$1,457	$2,653	$1,208	$1,126	$30,523	0.66	$20,171	$232,882
2024	$15,473	$10,460	$1,570	$2,857	$1,301	$1,212	$32,873	0.64	$21,132	$254,014
2025	$16,665	$11,265	$1,690	$3,077	$1,401	$1,306	$35,404	0.63	$22,140	$276,154
2026	$17,948	$12,132	$1,821	$3,314	$1,509	$1,406	$38,130	0.61	$23,195	$299,349
2027	$19,330	$13,067	$1,961	$3,570	$1,625	$1,515	$41,066	0.59	$24,301	$323,650
2028	$20,818	$14,073	$2,112	$3,844	$1,750	$1,631	$44,228	0.58	$25,459	$349,109

*Based upon a 7.7% Escalation Factor from KSC Facility Construction & GSE Cost Index (December 30th, 2007)
†Based upon 2.8% Discount Rate from OMB Circular A-94 (2008)

USA contractual costs and USA standing ground operation expenses were averaged for the years that were analyzed (FY 2001-2007). Direct corrosion control remediation activities were segregated by the asset type, except for research and NASA managerial expenses which were categorized as "Other".

Projected expenditures were calculated using equation 1, and were based upon the 7.7% escalation factor for facilities and Ground Support Equipment at the Kennedy Space Center. These calculations were then summed by year to produce an escalated yearly cost for corrosion remediation for the assets, and are shown in the "Total" column.

Each summed row was discounted to adjust the totaled value for the time value of money. This was performed in accord with equation 2, and utilized the 2.8% Real Discount Rate. This produces the "Present Value" of the future sum, and takes into account an investors desire to obtain a fixed amount of money today, as opposed to the same sum at a future time.

The Cumulative Net Present Value (CUM NPV) provides a running total that includes the prior years discounted costs. Consequently, at the end of a twenty year lifecycle, the cumulative cost of corrosion for the launch pads and MLPs is approximately 349 million dollars. This rapidly increasing yearly cost illustrates the need for:

1) technological investments that produce products to reduce corrosion.
2) corrosion preventative structural designs.
3) asset management and preventative processes aimed at addressing corrosion issues early in the life of the asset.

An analysis of the yearly corrosion costs in Table 3 suggests that improved materials, processes and structural designs can have a pronounced influence on the total lifecycle cost of corrosion.

The lifecycle analysis presented in this paper was used as a baseline study of corrosion costs and projections into the future. This information is useful to consider the dynamic (multi year) savings realized with potential corrosion control methodologies.

CONCLUSIONS

Interviews with NASA and USA personnel indicated that four major components of funding (for corrosion related costs) for LC 39A, LC 39B, MLP-1, MLP-2 and MLP-3 were present. They included USA Contracts, USA Standing Ground Operations, NASA Corrosion Control and Oversight, and Testing and Development. By far, the largest degree of funding for the assets in question was a function of USA contracts. Based upon the data, yearly maintenance and refurbishment costs were delineated. Through escalation and discounting, these values were extrapolated to future year costs. These

compounded costs show the dynamic reduction in lifecycle costs that can be realized with potential corrosion control methodologies.

ACKNOWLEDGEMENTS

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