

Launch Pad in a Box

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ABSTRACT

NASA Kennedy Space Center (KSC) is developing a new deployable launch system capability to support a small class of launch vehicles for NASA and commercial space companies to test and launch their vehicles. The deployable launch pad concept was first demonstrated on a smaller scale at KSC in 2012 in support of NASA Johnson Space Center's Morpheus Lander Project. The main objective of the Morpheus Project was to test a prototype planetary lander as a vertical takeoff and landing testbed for advanced spacecraft technologies using a hazard field that KSC had constructed at the Shuttle Landing Facility (SLF). A steel pad for launch or landing was constructed using a modular design that allowed it to be reconfigurable and expandable. A steel flame trench was designed as an optional module that could be easily inserted in place of any modular steel plate component. The concept of a transportable modular launch and landing pad may also be applicable to planetary surfaces where the effects of rocket exhaust plume on surface regolith is problematic for hardware on the surface that may either be damaged by direct impact of high speed dust particles, or impaired by the accumulation of dust (e.g., solar array panels and thermal radiators).

During the Morpheus free flight campaign in 2013-14, KSC performed two studies related to rocket plume effects. One study compared four different thermal ablatives that were applied to the interior of a steel flame trench that KSC had designed and built. The second study monitored the erosion of a concrete landing pad following each landing of the Morpheus vehicle on the same pad located in the hazard field. All surfaces of a portable flame trench that could be directly exposed to hot gas during launch of the Morpheus vehicle were coated with four types of ablatives. All ablative products had been tested by NASA KSC and/or the manufacturer. The ablative thicknesses were measured periodically following the twelve Morpheus free flight tests. The thermal energy from the Morpheus rocket exhaust plume was only found to be sufficient to cause appreciable ablation of one of the four ablatives that were tested. The rocket exhaust plume did cause spalling of concrete during each descent and landing on a landing pad in the hazard field. The

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concrete surface was laser scanned following each Morpheus landing, and the total volume of spalled concrete that eroded between the first and final landings of the Morpheus Project's test campaign was estimated.



Figure 1. (Left) Schematic of a transportable modular steel launch/landing pad with attached flame trench. (Right) Landing pad at KSC showing cumulative spalling of concrete produced during the descent and landing of the Morpheus vehicle after free flight #10.

This paper will also describe a new deployable launch system (DLS) capability that is being developed at KSC and was publicly announced in May 2015 (KSC Partnerships, 2015). The DLS is a set of multi-user Ground Support Equipment that will be used to test and launch small class launch vehicles. The system is comprised of four main elements: the Launch Stand, the Flame Deflector, the Pad Apron and the KAMAG transporter. The system elements are designed to be deployed at launch or test sites within the KSC/CCAFS boundaries. The DLS is intended to be used together with the Fluid and Electrical System of the Universal Propellant Servicing Systems and Mobile Power Data and Communications Unit.



Figure 2. A new deployable launch system (DLS) for small class vehicles at NASA Kennedy Space Center was made public on May 9, 2015.

DEPLOYABLE LAUNCH SYSTEM (DLS)

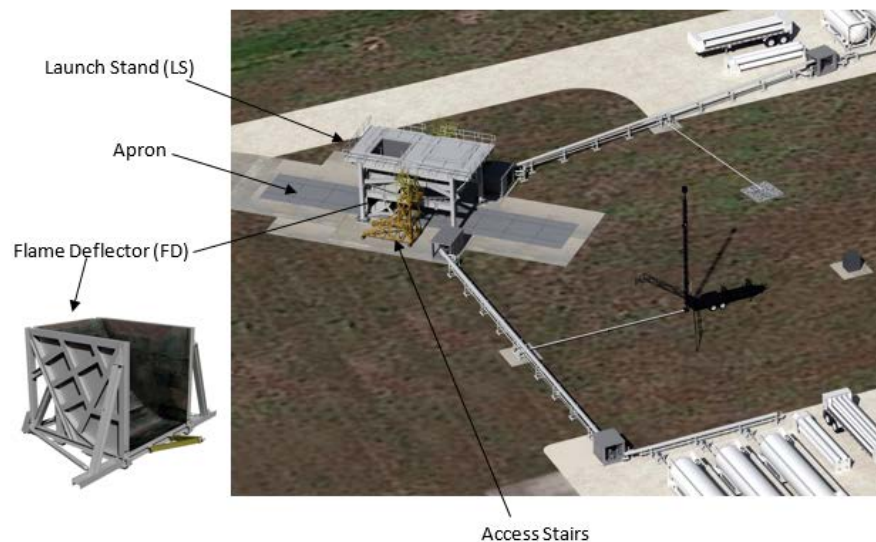
INTRODUCTION

NASA KSC has designed and partially built a new multi user, modular and transportable rocket launch pad. The system is the DLS and it provides a very flexible and low cost launching system which can be used for launching and testing of a wide range of small to medium class rockets. The DLS is not site specific it's a bolted construction and all the components can fit on flatbed trucks and transported to any site, thus the name "Launch Pad in a Box" was used to describe the modular transportable launcher.

The DLS design utilizes the latest innovation in launch pad design called "Clean Pad" which removes fixed service structures at the pad, which experience has shown to be expensive to maintain and modify. The Clean Pad approach gives the launch pad great flexibility and utility for reconfigurable multi mission capability. All of the functional components of the DLS are modular and can be moved to a protected storage/maintenance site, and/or replaced if future new mission requirements need to be met.

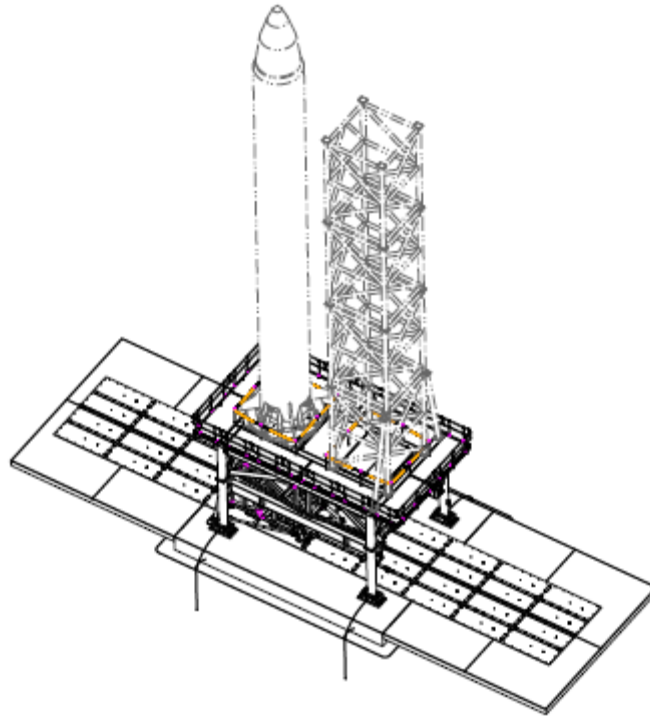
A concrete pad at the desired launch site is all that's needed to set up the DLS. Inside the perimeter of KSC's Launch Pad 39B this pad was constructed and is called Pad 39C, a description of which is given latter in this paper. An overview of the design and functional components of the DLS is presented below which show the versatility and utility of its unique and innovative capabilities.

The graphics below shows the DLS components as they would look installed at the launch pad.



Deployable Launch System Components at launch site

A full assembly of the DLS and a representative rocket and tower in a pre-launch configuration including capabilities and interface geometry of the DLS are given in KSC ICD (interface control document) drawing k0000070202d. Other operationally useful information can be found on Con-ops drawing k0000070201d which shows the information on moving and positioning the DLS on the pad and interfaces with the flame deflector.

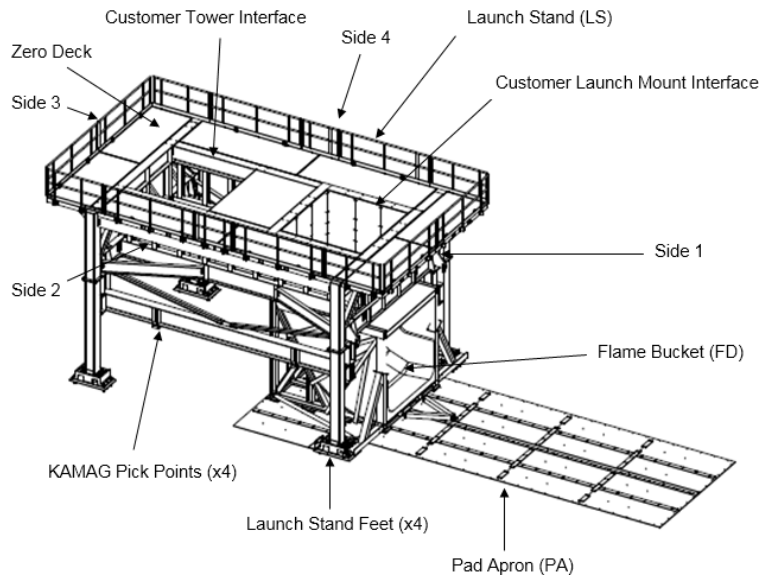


DLS with representative rocket and tower (from drawing k0000070202d)

DLS DESCRIPTION

The Deployable Launch System is a set of multi-user Ground Support Equipment (GSE) that are used to test and launch medium class launch vehicles. The system is comprised of four main elements: the Launch Stand (LS), the Flame Deflector (FD), the Pad Apron (PA) and the KAMAG transporter. KAMAG transporter is not required for a fixed installation and is only used to transport the assembled DLS to-and-from the launch pad and an assembly/processing facility if one is present. Each of these functional elements will be described in this section. The figure below shows the major functional elements of the DLS.

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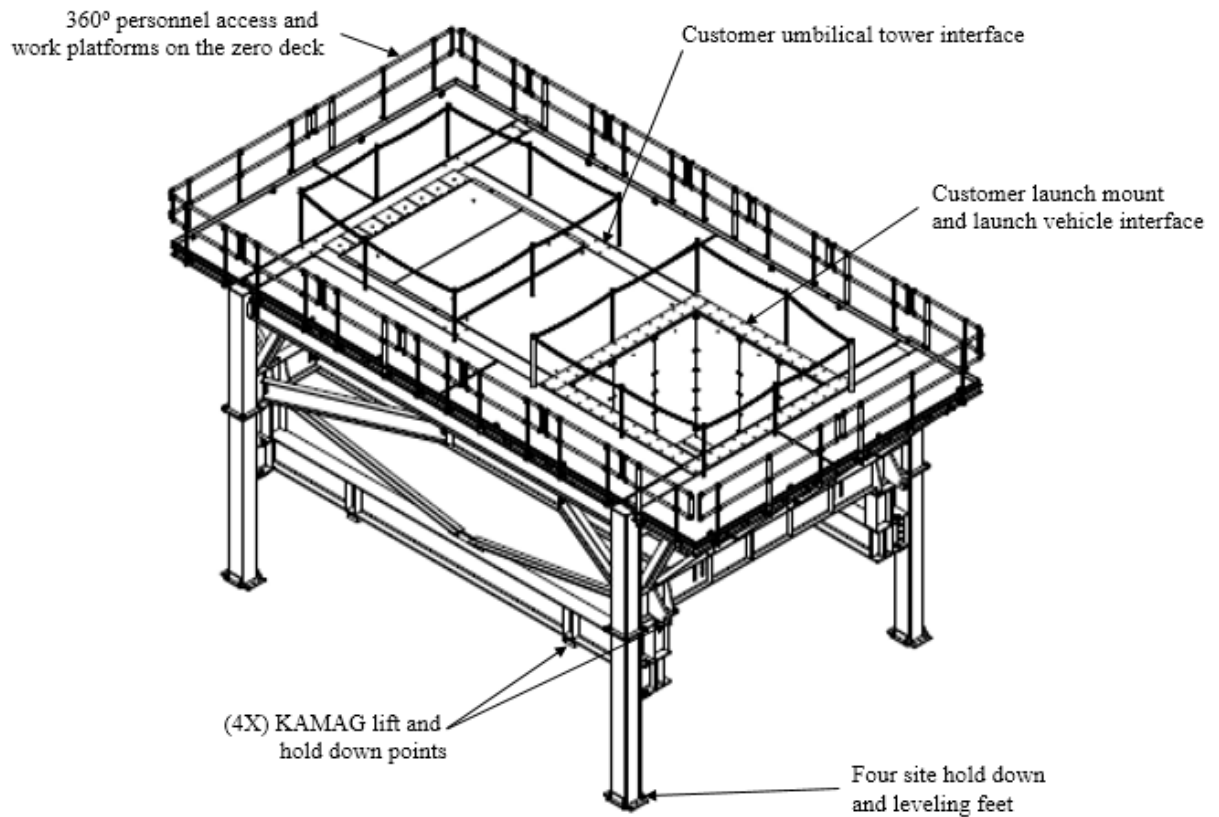
The Launch Stand (LS)

The LS is the central support structure to which the rocket and tower are attached and positioned for launch. The assembled LS is approximately 286 inch wide x 386 inch long x 283 inch high (7.26m x 9.8m x 6.05m) and weighs 86,000 lbm ((39,000 kg). The LS design is based on the time proven mobile launcher concept. It functions as the mobile platform which can be used to move the rocket/tower “stack” to and from the launch pad and assembly/processing facility. The LS is mobile with special hard points built in to be lifted and tied down to a commercial KAMAG vehicle (multi wheeled self-leveling, high load capacity, transporter), but if desired by the end user it can be permanently sited at the launch pad and some other means provided to bring the rocket out to the pad and stack it on the LS.

Typically, the LS would be transported to the assembly/processing facility where in a controlled protected environment the rocket can be stacked, assembled, payloads installed and checked out before transporting it to the pad for launch. In this scenario the rocket and payload are prepared for launch and roll out to the launch pad, fueling and launch can take as little as a few hours. The DLS is ideally suited to support this type of processing. It has leveling feet which can be installed in the processing facility to locate and level the structure before the rocket is stacked.

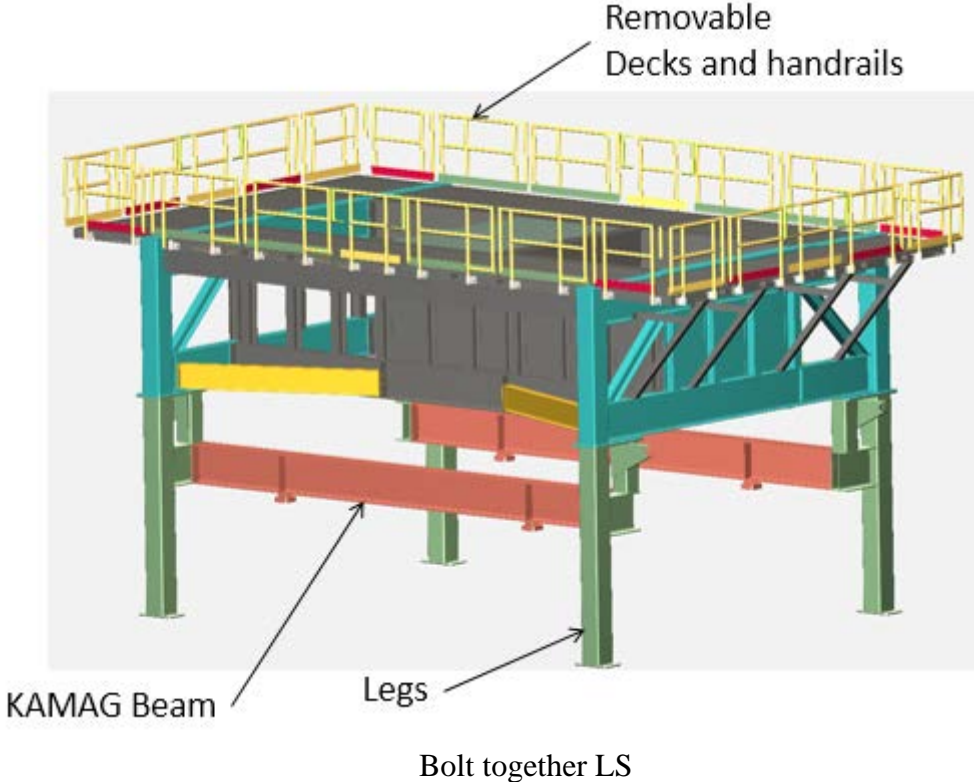
An alternative scenario is to bring the rocket and payload to the launch pad and using a crane or other lifting equipment raise and stack the rocket on the LS. This scenario is less costly since no processing facility is needed, but not often used because it's somewhat more prone to weather influences which can complicate the stacking, integration, and check out processes taking place at the pad typically outdoors. The DLS can support this type of operation as well, it has bolt down feet which can permanently attach it to the launch pad.

In the figures below the LS and its components are show illustration the main design features.



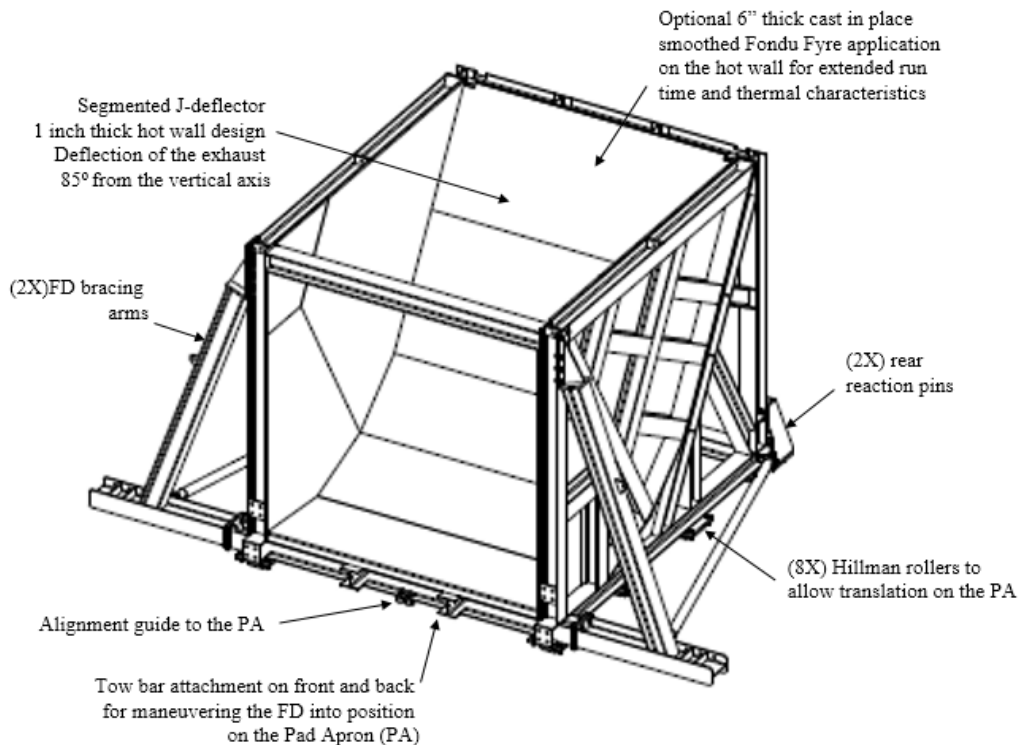
DLS Launch Stand (LS) components

The graphic below shows the separable components of the LS in different colors. Each of these components is bolted and can be separated for transport of the LS with standard flatbed trailers.



The Flame Deflector (FD)

The FD sometimes referred to as the “flame bucket” is the other major component of the DLS and is important to make it a fully functioning launch system. The fully assembled FD is approximately 292 inch wide x 193 inch long x 150 inch high (7.4m x 4.9m x 3.8m), and weighs 38,000 lbm (17,242 kg). The design of the DLS FD is unique and made to fit the overall mission profile of the system. Unique features include: it’s modular and transportable, it’s above ground, mobile on wheels, and it can be used for launching or long duration test firing. The figure below shows the FD assembly and major components.



The FD is modular and the support and attachment components like the bracing arms and reaction pins are bolt on. When removed these components and the main weldment are transportable over public roads on flatbed truck. This modular design meets the “Launch Pad in a Box” goal of modular transportable components.

The DLS FD is above ground which is different from many of the traditional launch pads where the FD is below grade and built into the surface of the pad. This design supports the Clean Pad concept and reduces the cost of construction. If in the future a new FD geometry is needed then this FD can be changed out without major facility modifications.

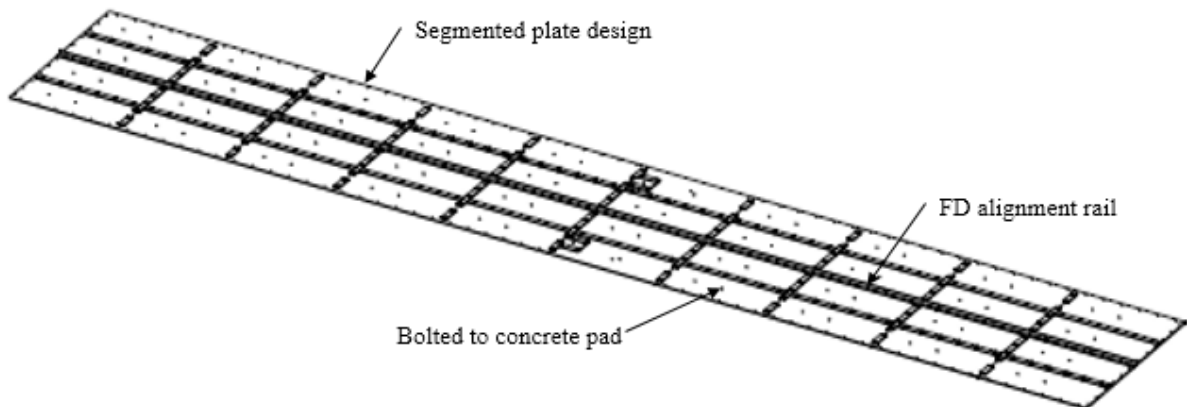
The FD is designed to roll in and out from under the LS. This allows for the transport of the LS where the KAMAG can drive under the LS and the FD is out of the way during this transport operation. In a fixed LS configuration the FD can permanently be left in place under the LS flame hole in which case this rolling feature would not be utilized. Movement of the FD is facilitated by tow a bar which can be attached to the front or rear of the FD. The tow bar can be hooked to a tow vehicle (any sufficiently sized fork lift or truck with standard Pintle hook hitch) to pull or push the FD. The FD rolls on (8) high capacity Hilman rollers (20 tons each) on the steel plates of the Pad Apron. The pad apron has a center guide rail to maintain the straight lie motion of the FD. This center guide facilitates alignment and positioning of the FD for repeatable insertion and removal from the LS.

THE PAD APRON (PA)

The PA is an integral part of the DLS and serves multiple functions. The PA is made from standard 48 inch wide x 120 inch long x 0.5 inch thick (1.22m x 3.05m x 0.013m) steel plates connected with bolter strips. The full apron assembly is 192 in wide x 1200 in long (4.88m x 35.5m) weight 19,800 lbm (9000 kg). Its primary function is to protect the concrete pad from the plume impingement heat damage that can result from the high temperature and velocity rocket exhaust.

The other function of the PA is to provide a hard smooth surface for the FD to roll on. It also has a guide rail that guides the FD as described above. In a fixed installation this feature of the PA would not be required and the size could be reduced to cover only the area in front of the FD and the center guide rail would not be needed

The figure below shows the PA assembly.



DLS SUMMARY

As described above the DLS is truly the Launch Pad in a Box and bring a new innovative design solution for launching small to medium class rockets. Its

modularity and ease of reconfiguring its components can meet any customers' needs for an efficient cost effective launch structure.

Morpheus Lander Plume Studies

KSC performed two tasks related to plume studies for the JSC Morpheus Lander's free flight tests at the KSC Shuttle Landing Facility. One task was to apply thermal ablatives to the interior of a steel flame trench that KSC designed, and then monitor the ablatives following each launch. The second task was to study the erosion of concrete following the landing of the Morpheus vehicle on a concrete landing pad.

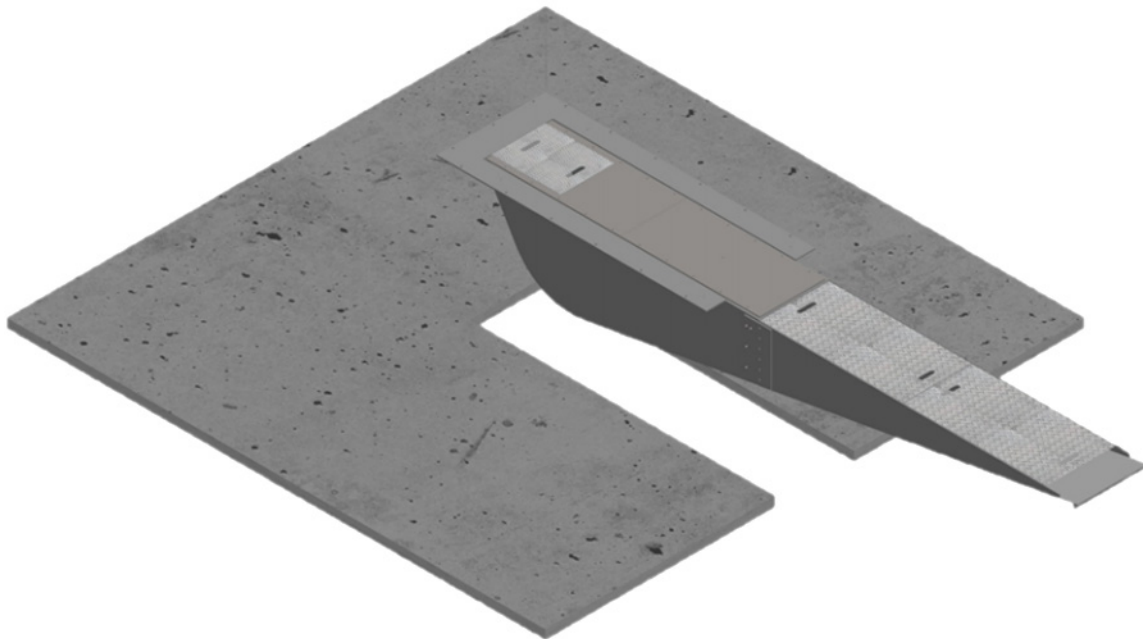


Figure 1. KSC designed a modular steel flame trench that could be attached to existing concrete and steel launch pads.

All surfaces of the portable Flame Trench that would be exposed to hot gas during launch of the Morpheus lander were coated with silicone ablative coatings. All products have been tested as ablatives by NASA KSC and/or the manufacturer (reference specification KSC-SPEC-F-0006). All products tested have performed equal to or better to SCM-3404-NASA.

The Flame Deflector portion of the Flame Trench was coated with trowable silicone ablatives to a nominal thickness of 0.250 inches. Specific products consisted of the following:

- A. Momentive SCM-3404-NASA, 1-part coating, applied by brush
- B. Chem Seal CS-3808, 2-part trowable ablative coating
- C. Dow Corning 3-6077, 2-part trowable ablative coating
- D. Dow Corning 93-104, 2-part trowable ablative coating

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- E. Momentive SCM-3404-NASA with 30% by wt Hy-Tech Thermal Solutions ThermaCels

All other surfaces of the Flame Trench were coated with Momentive SCM-3404-NASA to a thickness ranging between 40-90 mils depending on the location. This single component was applied in 3 to 4 coating applications of 25 mils per coat.

The plan for application of ablatives to the flame trench involved the following steps:

1. Zinc paint was prepared by wiping with deionized water and isopropyl alcohol using lint free wipers.
2. Primer was applied under the Dow Corning and Chem Seal products.
3. Dow Corning and Chem Seal products are trowable and were applied using a spatula to smooth the surface. SCM-3404-NASA is less viscous and was applied using a brush.
4. The slope of the flame deflector, 24 inches wide, 40 inch deep, 60 degree slope, was coated with ablative 0.20 inches thick. See Figure 4 below.
 - A. Momentive SCM-3404-NASA, 1-part coating, applied by brush
 - B. Chem Seal CS-3808 applied in a vertical strip, 6 inches wide x 40 inches long.
 - C. Dow Corning 3-6077 applied in a vertical strip, 6 inches wide x 40 inches long.
 - D. Dow Corning 93-104, applied in a vertical strip, 6 inches wide x 40 inches long.
 - E. Momentive SCM-3404-NASA, applied on remaining surfaces
5. All other surface of the interior of the Flame Trench were coated with Momentive SCM-3404-NASA to 0.125 inches thick.

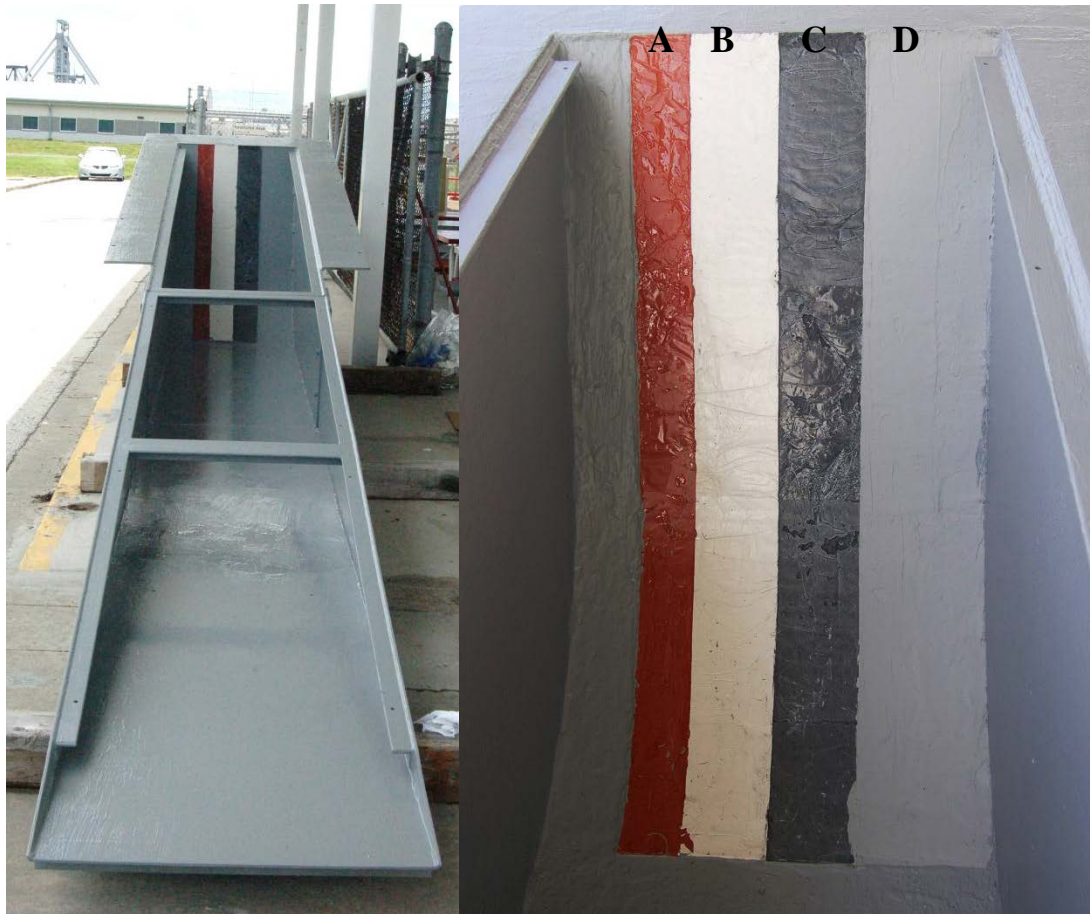


Figure 2. Ablative coatings applied to a coating of inorganic zinc paint inside the steel flame trench.

After twelve Morpheus free flight tests using the ablative coated steel flame trench, the Dow Corning 93-104 did not appear in Fig. 5 below to have been reduced in thickness at all according to ablative thickness measurements. The Chem Seal CS-3808 did ablate somewhat after each free flight launch, but as much as the other ablative materials. We conclude that the thermal energy from the Morpheus rocket exhaust plume was not sufficiently high enough to cause appreciable ablation of the Dow Corning 93-104 ablative, and thus was found to be the most suitable ablative for use with the Morpheus lander vehicle during launch.



Figure 3. Ablative coatings inside the steel flame trench after 12 Morpheus free flight launches.

During the descent and landing of the Morpheus lander on the concrete landing pad, a volume of concrete was eroded by spalling following each landing. After the last free flight, it was estimated that a cumulative volume of 0.1136 cubic meters of concrete had eroded between the first and final landing of the test campaign. The spalling was believed to be a result of water penetration into the concrete trapping the water which would suddenly vaporize and expand the concrete when the hot rocket exhaust gases transferred thermal energy to the concrete during descent and landing. It was noted that there was significantly less concrete erosion along the stress relief lines that were made in the concrete at the time it was originally poured and began to set.



Figure 4. The original concrete landing pad used for descent and landing of the Morpheus lander.



Figure 5. Physical state of the Morpheus concrete landing pad after free flight #10.



Figure 6. Setup used to laser scan the concrete landing pad following a Morpheus free flight. The laser scanner obtains a topographical mapping of a surface.



Figure 7. Determining the diameter of the eroded concrete and the erosion depth at various locations.

REFERENCES

KSC Partnerships, Center Planning and Development (2015). “Small Launch Vehicles.” <http://kscpartnerships.ksc.nasa.gov/Partnering-Opportunities/Launch-Systems/Small-Class-Launch-Vehicles>.