# MX Launcher Gas Generator Development

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**Four solid propellant gas generators were developed for the Missile X (MX) Loading Dock Launcher. Three internally mounted generators were designed to power pneumatic actuators which would raise, stabilize, and elevate the Launcher. A fourth water-cooled gas generator was developed to eject the missile out of the Launcher canister. Prototype systems were built and tested for each of the two generator concepts. Preliminary test results included in the paper show the validity of both concepts. Analyses have also shown that both concepts would significantly reduce Launcher life cycle cost.**

## Introduction

THE canisterized MX breakout, erection, and launch concept was successfully demonstrated in the 1970s. In early tests,[1] hot exhaust products from a solid propellant gas generator were used to eject a missile out of a canister, as shown in Fig. 1. In later tests,[2] externally mounted, solid propellant gas generators were used to power pneumatic actuators which erected a missile canister to the launch position through the roof of an underground horizontal shelter, as shown in Fig. 2. In mid-1980, the MX basing mode was changed from breakout and erection to the loading dock concept shown in Fig. 3. An evaluation of breakout and erection program results against loading dock requirements revealed that significant improvements could be made in both types of gas generators. An expensive and heavy protective plate could be eliminated from the MX first stage by cooling the exhaust gases of the launch eject generator. Similarly, by mounting the pneumatic generators internally within their respective actuators, the cost and weight of the Launcher could be significantly reduced. Based upon detailed life cycle cost analyses, a decision was made in mid-1980 to develop the water-cooled launch eject gas generator and the three internally mounted actuator generators described in this paper.

## Loading Dock Concept

In the MK Loading Dock Concept, shown in Fig. 3, the MX Missile was to be launched within 105 s of the launch command. To comply with this requirement, numerous events were sequenced to occur within the time periods shown in Fig. 4. In four of the events, gas generators were to be employed to power pneumatic actuators and to eject the missile from the canister. The pneumatic actuators were to deploy and support the roof reaction and center strut roller assemblies and erect the canister to the launch position. These three events require a total of 60, 45, and 20 s, respectively. The roof reaction and center strut gas generators were to operate for their entire respective time periods, while the erector generator was to operate for only half of the approximately 1.2 s it took to eject the missile from the canister.

## Requirements

All MX Launcher gas generators were designed to operate within the environments shown in Table 1. In addition, the generators were designed to have a service life of 10 years and a shelf life of 15 years. Their operational reliability was between 0.999 and 0.999974, and no maintenance was to be required during their 10-year service lives. Toxic combustion products were to be kept to a minimum and all grains were protected against the environment and contaminates. Ignition was to be accomplished by the explosive output of redundant through-bulkhead-iniatiators (TBIs). The malfunction of a single TBI would not degrade the performance of the gas generator igniters. All generators were designed to have minimal size and weight impact upon the Launcher.

In addition to the above requirements, the launch eject gas generator (LEGG) also complied with the system requirements shown in Table 2.

The three actuator gas generators (cartridges) were to be mounted within their respective actuators. The actuator walls were to serve as gas generator cases, thus eliminating the need for the traditional dedicated generator cases. The gas generators were to operate unchoked and exhibit stable burning at all pressures up to 6000 psia. Their maximum flame temperatures were to be below 2500°F to ensure compatibility with the actuators. All three generators were designed so their respective actuators could be easily cleaned, refurbished, and fitted with new grains after each firing. Access to the generators was to be through the actuator end closures, which was to house also the gas generator igniters.

### Launch Eject Gas Generator

The launch eject gas generator (LEGG) was mounted within the aft end of the canister, as shown in Fig. 5. To minimize canister length, the LEGG was nestled inside the first-stage motor nozzle and maintained a minimum clearance of 5.5 in. to avoid nozzle damage. The LEGG produced the launch pulse shown in Fig. 6 by mixing the exhaust gases of a hot gas generator with water. The resulting gas, steam and water mixture provided the energy required to eject the missile from the canister while maintaining a temperature that will not damage the missile nor cause auto ignition of the first-stage motor. An operational cutaway of the LEGG is shown in Fig. 7. As can be seen in this figure, the exhaust products of the hot gas generator passed through the standpipe assembly and pressurized the water within the coolant chamber by means of holes in the double-walled standpipe. Water from the collant chamber was then injected into the exhaust gases at the lower end of the standpipe. The resultant mixture of gas, steam, and water was further mixed by the exhaust manifold before it was released into the canister, where it produced the required launch gas pressure. The complete LEGG, including water, weighed approximately 10,000 lb.

To produce the required launch pulse, the hot gas generator operated for approximately 0.7 s at a pressure of 3340 psia and a flame temperature of 4860°F. The propellant grain was 23.5 in. in diameter and 16.6 in. long. It weighed ap-

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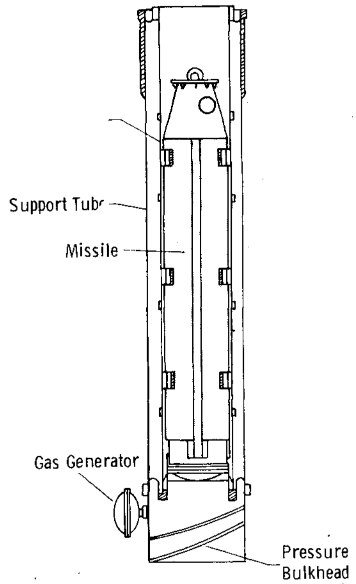



**Fig. 1 MX peashooter canister and missile.**

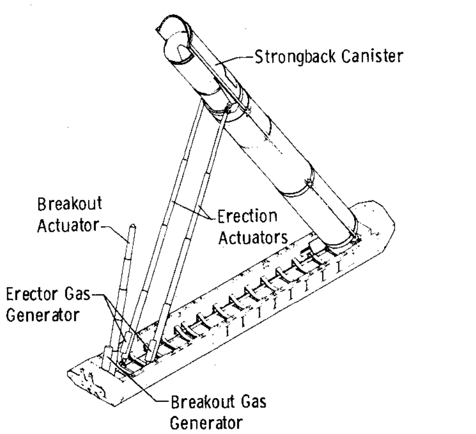



**Fig. 2 MX breakout and erection Launcher configuration.**

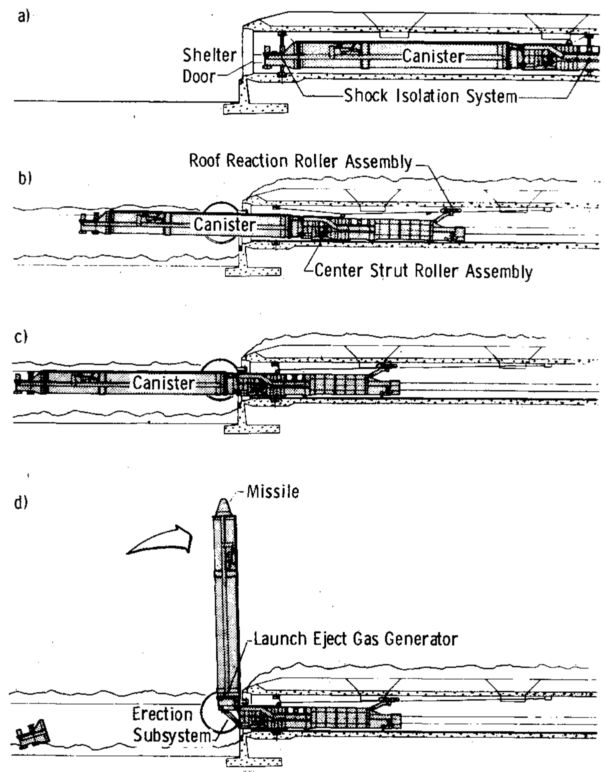



**Fig. 3 MX loading dock launch sequence.**

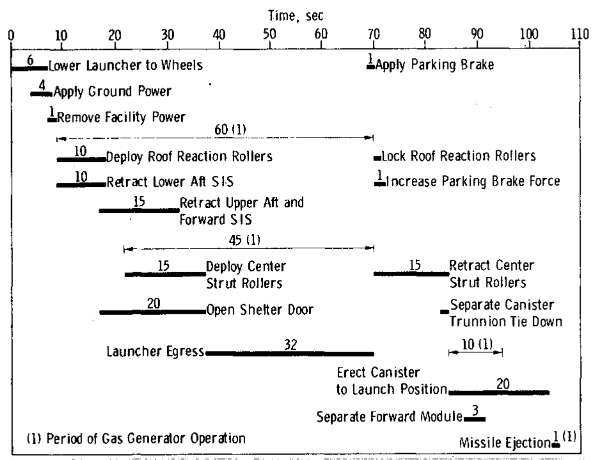



**Fig. 4 MX Loading Dock Launcher timelines.**

proximately 330 lb and produced a 540 lb/s mass flow rate by means of an extremely progressive burning surface. The burning surface consists of the aft end of the grain plus the inner surfaces of twenty-six 1.5-in. dia. holes that ran the length of the grain. The grain was cast into a steel sleeve that was suspended within the 4340 steel case. $BKNO_3$ pellets were used for ignition. The hot gas generator produced pressures between 3250 and 3520 psia while operating within the temperature extremes of +45 and +100°F. A graphite nozzle was used to decouple the hot gas generator from the remainder of the LEGG assembly.

An ammonium perchlorate CTPB propellant was selected for the LEGG. This propellant was demonstrated during the MX Canister Advanced Development and MX Peashooter Eject Gas Generator Programs. It has a burn rate and pressure exponent of 2.0 in./s and 0.5, respectively, at 2000 psia, and its temperature sensitivity ($\pi K$) is 0.16%/°F. The propellant family has a 10-year demonstrated service life.

## Actuator Gas Generators

### Erection

The erection gas generator was to provide power to the erection actuator that elevated the canister and missile to the launch position, as shown in Fig. 8. The gas generator was to be mounted within the last stage of the erection actuator and was to react the actuator loads shown in Fig. 9. The maximum load occured initially as the erection system started to raise the cantilevered canister, missile, and forward shock isolation system (SIS) from the horizontal position. Once the Launcher forward section started to move upward, the force required to raise it fell off considerably. The actuator load was further reduced by the jettison of the SIS at approximately 10 deg of elevation. The loads fell off less drastically after 1 s of operation due to a combined reaction of actuator staging, angle of applied erection forces, and canister dynamics. At approximately 5 s, the actuator loads increased due to damping in the actuator third stage.

To satisfy this load profile, the erection gas generator was to operate for approximately 10 s and attain a nominal pressure of 4200 psia, as shown in Fig. 10.

The design shown in Fig. 11 was to utilize less than 19 in. of the available 40 in. length and weigh approximately 105 lb. A slightly regressive burn was to be obtained by the double-slotted center perforated/end burning grain configuration. The freestanding grain was to be supported within the actuator third stage by an end plate that was to be retained between a step in the third-stage wall and the actuator end closure. The grain was to be sealed on both ends to protect it

**Table 1 MX Launcher gas generator**

| Environment | Operating | Nonoperating |
|---|---|---|
| Temperature limits, °F | +45 to 100 deg[a] | −58 to +126 deg |
| Humidity | 3 to 100% | 3 to 100% |
| Mechanical shock (maximum) | 2.2*g* vertical 1.1*g* horizontal | ... |
| Vibration, rms | 4.5*g* all three orthogonal axes | ... |
| Nuclear shock (maximum) | 30.0 *g* all three orthogonal axes | ... |

[a] All hot gas generators will be validated from +27 to +118°F.

**Table 2 Launch eject performance requirements**

| | |
|---|---|
| Missile exit velocity | 120±40 ft/s |
| Maximum missile acceleration | 6.5 g |
| Maximum acceleration rate of change | 67 g/s |
| Maximum canister pressure at missile exit | 200 psia |
| Maximum gas/steam temperature inside stage 1 aft dome | 450°F |
| Average gas/steam temperature outside stage 1 aft dome | 550°F |
| Maximum pressure across aft dome | 150 psia |

from actuator contaminates. The grain outer diameter was to be protected by a nylon epoxy inhibitor. Ignition was to be accomplished by a 2.8-lb igniter. The igniter exhaust was to be directed into the central part of the grain cartridge. Upon ignition, the forward seal would be broken and shortly thereafter, the aft urethane foam seal support and aluminum seal would be consumed. Neither a nozzle/orifice plate nor a gas generator case would be required in this design.

The propellant used in this design was an ammonium perchlorate PBAN which came from a family used in the Army Up-STAGE and MX Buried Trench Weapon System Programs. It has an adiabatic flame temperature of 2438°F and nominal burn rate and pressure exponent of 0.49 in./s and 0.47, respectively, at 5000 psia. Its temperature sensitivity ($\sigma p$) is 0.091%/°F. The propellant family has a 10-year demonstrated service life.

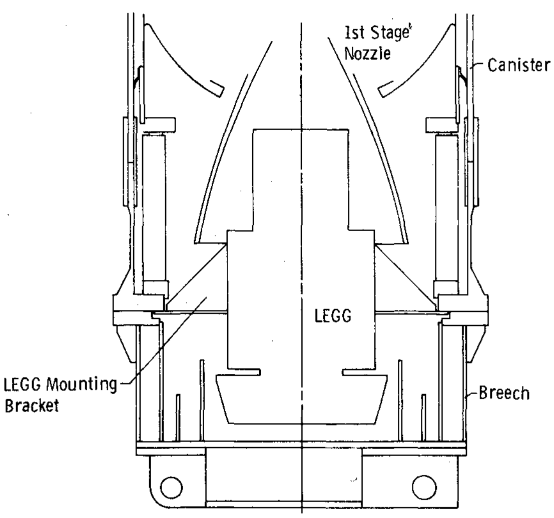



**Fig. 5 Launch eject gas generator position within canister.**

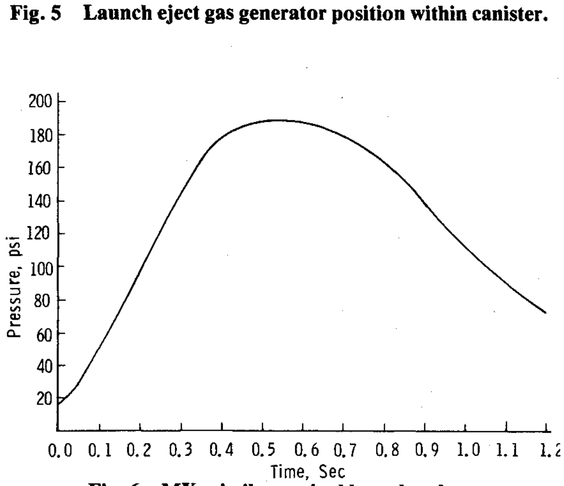



**Fig. 6 MX missile nominal launch pulse.**

**Center Strut**

The center strut gas generator was to provide power to the actuator that fully deployed and supported the center strut assembly during wartime Launcher egress, as shown in Fig. 12. There were to be two center strut roller assemblies, two actuators and two gas generators per launcher vehicle. The gas generators were to be mounted within the smaller actuator stage and produce the nominal pressure and mass flow rates shown in Fig. 13. They were to operate for approximately 45 s each and maintain the pressure within the actuator between 4500 and 5500 psia over this time period. As can be seen in Fig. 13, the gas generators were to pressurize the actuators to a nominal pressure of 5000 psia within 4 to 5 s and then produce just enough mass flow (7 to 10%) during the remaining 40 to 41 s to replace actuator heat losses.

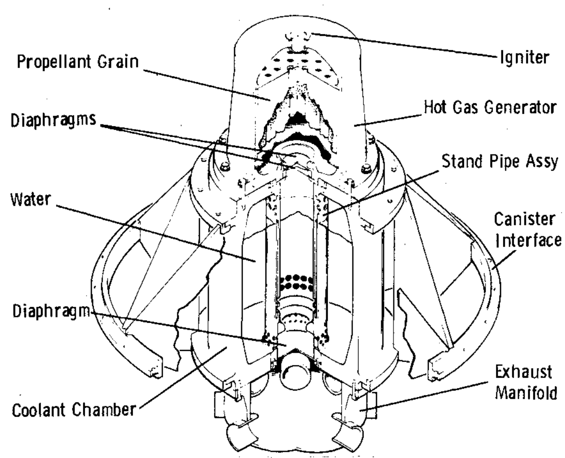



**Fig. 7 Launch eject gas generator.**

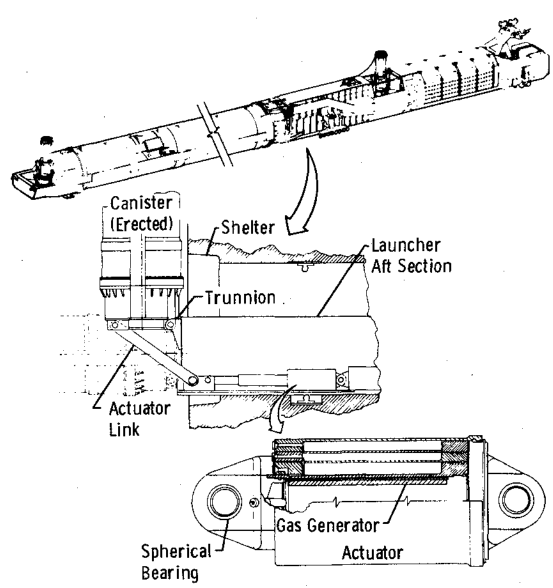



**Fig. 8 Erection subsystem.**

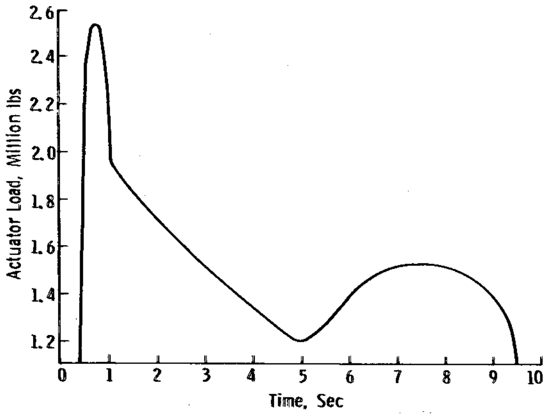



**Fig. 9 Erection actuator loads vs time.**

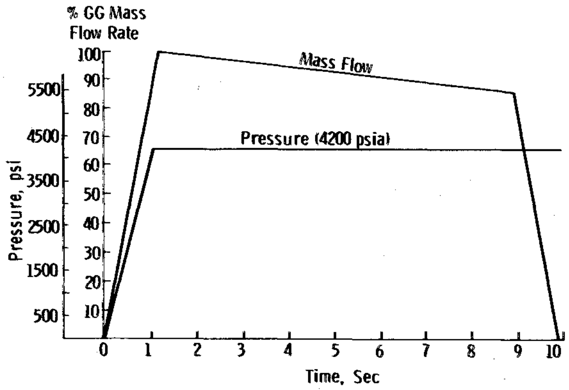



**Fig. 10 Erection gas generator mass flow and pressure vs time.**

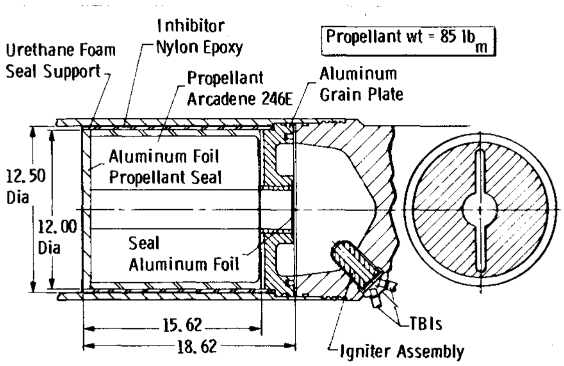



**Fig. 11 MX launcher erection gas generator.**

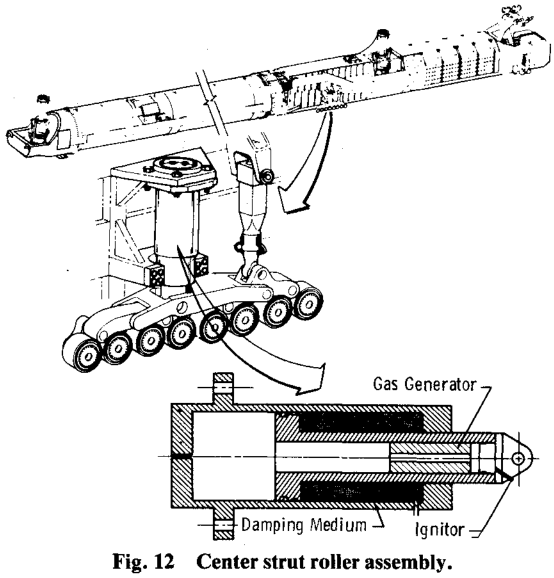



**Fig. 12 Center strut roller assembly.**

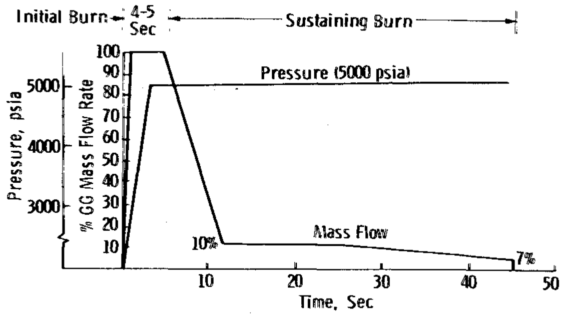



**Fig. 13 Center strut gas generator mass flow and pressure vs time.**

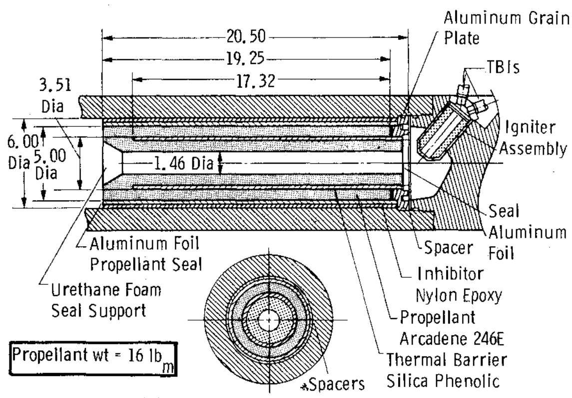



**Fig. 14 MX center strut gas generator.**

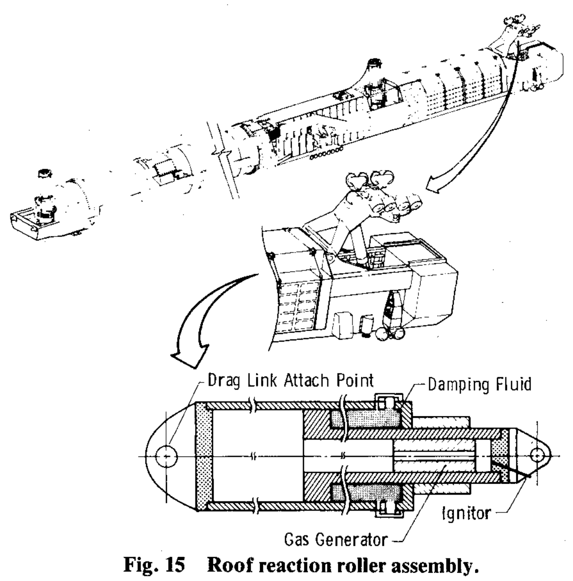



**Fig. 15 Roof reaction roller assembly.**

The center strut gas generator design shown in Fig. 14, weighed approximately 25 lb. The required mass flow was to be obtained by a highly progressive burn for the first 4 to 5 s and then a neutral end burn for the remaining 40 to 41 s. Initially, the entire center bore and aft end were to be ignited. As the center bore and aft grain end burnt back toward the silica phenolic tube, the burning surface would transition into a "doughnut" end burning configuration. Again, the freestanding grain cartridge was to be held in place between a step in the actuator wall and the actuator end closure. As in the erection gas generator design, both ends of the grain were to be sealed and the outer diameter was to be protected by a nylon epoxy inhibitor. Similarly, both the main grain and the igniter were to utilize the erection propellant. The igniter configuration was also to be identical to the one used on the erection gas generator.

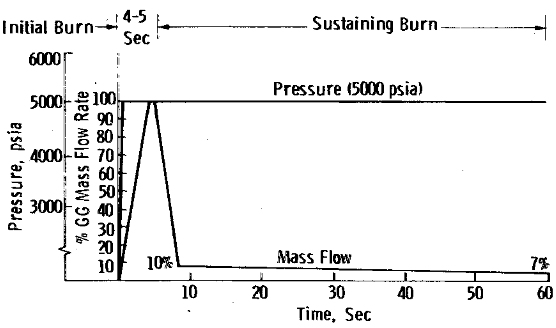



**Fig. 16 Roof reaction gas generator mass flow and pressure vs time.**

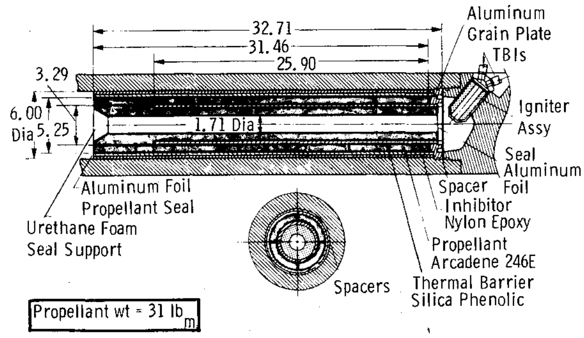



**Fig. 17 MX Launcher roof reaction gas generator.**

### Roof Reaction

The roof reaction gas generator was to provide power to the actuator that deployed and supported the roof reaction roller assembly during Launcher wartime egress, as shown in Fig. 15. The gas generator was to be mounted within the actuator in the same manner as was the center strut generator and produce the nominal pressure and mass flow rates shown in Fig. 16. The gas generator was to operate for approximately 60 s and maintain an actuator pressure between 4400 and 5500 psia for this time period. A nominal actuator operating pressure of 5000 psia was to be reached within 4 to 5 s of ignition. A sustained burn for 55 to 56 s at a reduced mass flow of 7 to 10% was then to be maintained to make up for the actuator heat losses.

The roof reaction gas generator design shown in Fig. 17 was to be 5.25 in. in diameter, 32.71 in. long and weigh approximately 44 pounds. As in the center strut design, the required mass flow was to be obtained by a highly progressive initial burn which would transition into a "donut" end burner. The gas generator cartridge was to be held in place in the same manner as the two previous generators. Likewise, the grain was to be sealed at both ends and protected at its outer diameter by a nylon epoxy inhibitor. The ignitor was to be the same one used by the other two gas generators, as was the gas generator propellant.

**Table 3 Life cycle cost comparison between hot gas and water-cooled gas generators**

| Program phase | Delta cost—hot gas LCC minus water-cooled gas LCC (1978 $) |
|---|---|
| Development | $ 3M |
| Production | −22M |
| Operation | 46M |
| Total | $ 27M |

**Table 4 Life cycle cost comparison between externally and internally mounted gas generators**

| Cost factor | Delta cost-external LCC minus internal LCC (1982 $) |
|---|---|
| Acquisition | |
| Propellant | $ 0 |
| Hardware | $ 1.6M |
| Weight ($5K per lb) | $14.7M |
| Total | $16.3M |

**Table 5 Weight comparison between externally and internally mounted gas generators**

| System (number of units per Launcher) | Weight, lb External | Internal | Delta |
|---|---|---|---|
| Erection gas generation (1) | 1140 | 105 | 1035 |
| Center strut gas generator (2) | 1110 | 50 | 1060 |
| Roof reaction gas generator (1) | 895 | 44 | 851 |
| Total weight (per Launcher) | 3145 | 199 | 2946 |

## Trade Studies and Analyses

### Launch Eject Gas Generator: Life Cycle Cost

A life cycle cost (LCC) analysis was performed to determine the cost difference between hot gas and water-cooled gas generators. The factors considered in this analysis were gas generator, canister refurbishment, mass simulator, transportation and handling, and sabot (first-stage heat shield) costs. The cost impacts on the Launcher structure and the shelter were also considered. All factors were evaluated for the three major phases of the MX program. The results of the analysis are summarized in Table 3.

As can be seen in Table 3, the water-cooled generator cost more to produce than the hot gas system. However, the savings in canister refurbishment (operational phase) and in eliminating the sabot more than offset the additional production costs.

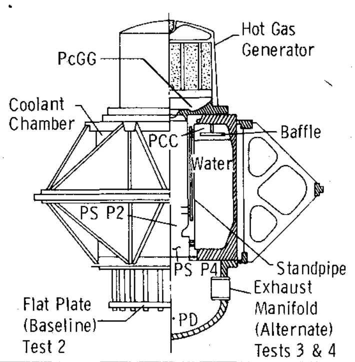
### Actuator Gas Generators: Life Cycle Cost

A life cycle cost trade study was also performed to determine the cost difference between externally and internally mounted actuator gas generators. It was assumed that both systems would have a 10-year service life and thus neither would require maintenance. Spare requirements and reliability were also found to be approximately equal. Likewise, impact upon Launcher cost ($19M/in. increase in diameter and $9M/ft increase in length) was determined to be negligible in both systems. The LCC analysis was therefore reduced to a comparison of acquisition and Launcher weight cost impacts, as shown in Table 4.

Based upon this analysis, it was shown that the life cycle cost of the actuator gas generators would increase approximately 182% if they were externally mounted.

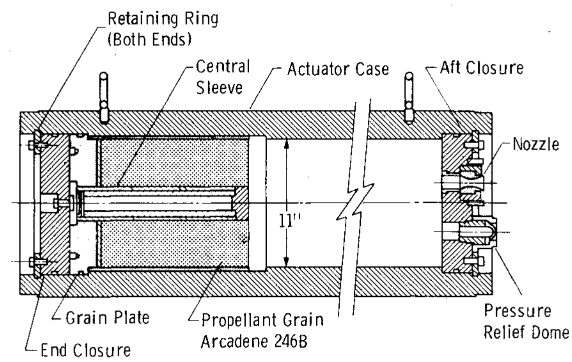
### Weight

An analysis was performed to determine the weight difference between the externally and internally mounted gas generators, since every pound added $5000 to Launcher life cycle cost. As would be expected, the externally mounted units weighed considered more (1480%) than the internal ones due to the addition of external cases and manifolds. Results of the analyses have been summarized in Table 5 for each Launcher system.




| Pressure (PSIA) | Design | Test 1 | Test 2 | Test 3 | Test 4 |
|---|---|---|---|---|---|
| PCGG | 3,340 | 3,590 | 3,520 | 3,580 | 3,600 |
| PSP2 | 2,200 | 1,900 | 2,100 | - - | 2,400 |
| PCC | 2,150 | 1,350 | 1,650 | 1,650 | 2,250 |
| PSP4 | 650 | 550 | 600 | 550 | 810 |
| PD | 550 | 100 | N/A | 550 | 750 |
| Inject ΔP | 1,500 | 800 | 1,050 | 1,100 | 1,440 |

**Fig. 18 Launch eject gas generator prototype No. 1 test results.**




| Design | Test Motor No. 1 | Test Motor No. 2 |
|---|---|---|
| Grain Outside Diameter, in. | 11.0 | 11.0 |
| Grain Inside Diameter, in. | 1.225 | 1.225 |
| Grain Length, in. | 12.55 | 15.89 |
| Propellant Weight, 1 bm | 62.2 | 75.4 |
| Simulated Actuator Volume, $in.^3$ | 5000 | 5000 |

**Fig. 19 Demonstration gas generator and test fixture.**

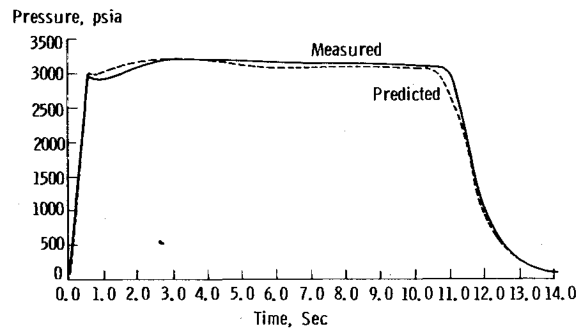



**Fig. 20 Gas generator demonstration test.**

## Prototype Test Results

### Launch Eject Gas Generator

To demonstrate hardware survivability, verify the validity of the water-cooled gas generator design concept, and identify potential problems, a full-scale LEGG prototype assembly was designed, fabricated, and tested. In this assembly, the coolant chamber, standpipe, and exhaust manifold designs were simplified to expedite fabrication. In addition, an existing "MX Peashooter" hot gas generator case was modified to accept the larger water-cooled gas generator grain. Various standpipe and exhaust manifold configurations were tested to determine their effect on overall system performance. The results of the four tests are shown in Fig. 18. As shown in this figure, the results of the first three tests were quite similar. In each of these tests, the water injection pressure was lower than predicted due to a lower than expected coolant chamber pressure (PCC). Analyses have shown that this pressure loss was caused by flow restrictions in the standpipe annulus and by the violent mixing, and subsequent cooling, of the hot gases with the coolant chamber water. To correct these anomalies, the cross-sectional area of the standpipe annulus was increased and gas baffles were installed in the top of the coolant chamber for Test 4. As shown in Fig. 18, with these correctives, Test 4 pressures showed excellent agreement with predicted (design) values. All the potential problems identified during these tests, as well as the actions taken to correct each concern, are shown in Table 6. Incorporation of these design fixes into the second generation assemblies will enable the LEGG to comply even closer with system performance requirements.

**Table 6 Prototype LEGG test concerns and solutions**

| Concern | Corrective action |
|---|---|
| Upper burst disc fragments expelled<br>System impact: Stage 1 grain subjected to hot fragments | Incorporate consumable or nonfragmenting burst disc |
| Propellant slivers expelled at HGG burnout<br>System impact: Potential post-test safety hazard | Redesign HGG grain |
| Low coolant chamber pressure<br>System impact:<br>Mixing may be impaired<br>Potential energy loss<br>Low water to gas mass flow ratio | Install gas baffle and reduce standpipe annulus gas flow resistance |

### Actuator Gas Generators

To demonstrate the basic actuator gas generator design concept, two full-scale grain assemblies were built and fired in the actuator test fixture shown in Fig. 19. Both assemblies utilized the same propellant and nylon epoxy inhibitor. The major design parameters are summarized in Fig. 19. Test results have been presented in Fig. 20. As can be seen in this figure, the measured and predicted curves show excellent agreement.

After each test the test fixture was swept out and washed with plain water. The debris collected during the refurbishment process was found to be a very fine particle carbon residue or "soot."

## Summary and Conclusions

### Launch Eject Gas Generator

The water-cooled gas generator described herein satisfied all Loading Dock MX Launcher requirements at the lowest life cycle cost. A prototype assembly was used to identify shortcomings in the LEGG design and appropriate corrective actions were implemented. The early prototype tests, thus, lowered overall LEGG program risks as well as proved the validity of the design concept.

**Actuator Gas Generators**

The internally mounted gas generators described herein offer simple, lightweight, low cost, flexible and adaptive designs which satisfied Loading Dock MX Launcher requirements. They made use of off-the-shelf technology and a well-proven propellant. Commonality between the various generator designs was maximized, while impact upon Launcher weight and life cycle cost was kept to a minimum.

1) Internally mounted gas generators offered a significantly lower life cycle cost than externally mounted units. For the three Loading Dock MX Launcher actuator gas generators, this savings was over 180% for their total estimated life cycle cost.

2) Internally mounted gas generators were considerably lighter than external units. This weight savings was over 1480% for each MX Launcher vehicle.

3) Internal units met all Loading Dock MX Launcher actuator gas generator requirements.

4) Internal gas generators provided the least impact upon MX Launcher size, weight, and cost.

5) Internal gas generators were better protected from hostile environments than externally mounted units.

## References

[1] Cummings, W.L., Reed, D.R., Thomas, E.L., and Reardon, J.E., "MX Canister Eject Gas Generator," *Proceedings of the 1979 JANNAF Propulsion Meeting*, Chemical Propulsion Information Agency Report No. 300, Vol. 1, March 1979.

[2] Park, L.T., "MX Breakout and Erection System Development," *Proceedings of the 1979 JANNAF Propulsion Meeting*, Chemical Propulsion Information Agency Report No. 300, Vol. 1, March 1979.