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PYRO THRUSTER FOR PERFORMING ROCKET BOOSTER ATTACHMENT, DISCONNECT, AND JETTISON FUNCTIONS

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ABSTRACT

The concept of a pyro thruster, combining an automatic structural attachment with quick disconnect and thrusting capability, is described herein. The purpose of this invention is to simplify booster installation, disengagement, and jettison functions for the U.S. Air Force's Advanced Launch Systems (ALS) program. A principal objective of the ALS program is to significantly reduce space transportation costs from those incurred with present launch vehicle systems.

INTRODUCTION

This pyro thruster study was made in support of the ALS program's charter, to create an economical and affordable "next-generation" space transportation system. ALS will provide routine access to space for large payloads in less than three weeks launch processing time, and will have higher reliability and safety standards than current expendables.

The payload delivery cost per pound to orbit will be reduced 90 percent compared to Titan IV recurring costs. Titan IV represents the benchmark for the ALS cost-reduction goal. This goal, as mandated by Congress, is defined as the average cost per pound of payload delivered to the ALS mission model, scheduled in the beginning of the 21st century.

This tenfold reduction of recurring costs in the area of manufacturing and launching the ALS will be achieved by using increased launch vehicle size, simplified vehicle configuration, higher production rates, larger production quantities, and improved business, competition, and management practices. Significant technical contributors to the cost reduction include incorporation of appropriate new technologies and producibility improvements; emphasis on robustness built into a simple design to obtain higher reliability; cost-effective application of reusability techniques; and a practical, high-level automation of the vehicle integration and launch processes.

This cost reduction goal must also be reachable in terms of nonrecurring costs, up-front investments, and automation such as robotics and artificial intelligence.

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TECHNICAL DESCRIPTION

A typical arrangement for the booster aft and forward attachments to the core is shown in Figures 1 and 2, respectively. Each booster is attached to the core by two ball joints aft and one ball joint at the front of the booster. Each ball joint is attached to the housing of a pyro thruster by a collet chuck that has four collet grips, as illustrated in Figure 3. The four collet grips are seated in a slotted and grooved nut and are held in the locked position by a plug threaded to the piston rod. The ball race block has the shape of a stepped cylinder. It is lowered into the mating groove of the core's retainer block and latched in place automatically, as shown in Figures 3 and 4.

One of the two aft thruster housings branches out into three struts, forming a tripod. The ends of the tripod are pinned to the booster through monoballs, as shown in Figure 1. The tripod provides stability for the booster.

The other aft thruster housing branches out into two struts, forming a bipod. The bipod ends are pinned to the booster through monoballs (see Fig. 1). The bipod serves as a sway arm, allowing for relative motions between booster and core diameters.

Figure 2 depicts the forward attachment. The forward ball joint at the core interface is similar to the aft interface. The forward thruster housing branches out into a pivoting fork. These fork ends are pinned to the booster through monoballs. The pivoting fork, in combination with the thruster's ball joint, allows for large relative motions between booster and core along the longitudinal axes.

The pyro thruster has dual cartridges (see Fig. 3) to assure single-failure-tolerant jettison function. Booster disengagement and jettison are initiated by a guidance and control staging command to the laser fiber-optic controller. Disengagement occurs after cartridge ignition develops gas pressure, which forces the piston rod to unlock the collet plug. This causes the collet grips to collapse into the plug recess, unlocking the load-carrying ball. Increasing piston pressure rams the rod against an energy-absorbing stop, causing the thruster housing to move away from the interface. Thrusting characteristics are tailored to minimize shock (see Fig. 5).

The separation system is single-failure-tolerant for the separation function and dual-failure-tolerant against inadvertent pyro firing. High reliability is achieved through a simple, robust design, maximizing the use of proven technology and hardware.

All interfaces, including electrical umbilicals, are simple and accessible to facilitate installation, maintainability, and replaceability. No alignment or adjustment is required during installation; interfaces of all mating components are prealigned at factory level.

OPTIONS AND TRADE STUDIES

The following separation methods and combinations thereof have been investigated, and corresponding trade studies have been performed:

- Separation motors such as solid propellant staging rockets are costly, heavy, and inefficient.
- Of existing technologies, pneumatic pistons come closest to pyro thrusters, but have more parts and therefore less reliability.
- Coil or disk springs are large, heavy, and difficult to install.
- Kinematic methods (hinged booster aft attachment) require a large pivoting envelope.
- Mechanisms such as power-driven ganged latches, collets, or ball locks operated by ganged power hinges are complicated and heavy, with low reliability.
- All of the above-mentioned methods require additional explosive bolts or nuts, which increases complexity and cost while lowering reliability.

In commonly accepted practice, the booster disengagement and jettison functions are powered by separate energy sources. The structural joints are severed by pyrotechnic means, and then the booster is jettisoned using suitable thrusters. In most cases, the booster-to-core vehicle installation is difficult and requires time-consuming alignment operations.

The pyro thruster affords many advantages over other separation methods. The pyro thruster:

- Eliminates pyro fasteners at the three interface joints (such as explosive nuts or bolts)
- Is an integral part of the attachment structure
- Disengages the interface joint and performs the separation and jettison functions in one continuous stroke
- Requires minimum installation time (no alignment during installation)
- Reduces weight and cost
- Increases reliability
- Offers trouble-free producibility.

A novel feature of the pyro thruster is the incorporation of a unique and simple collet chuck, which is ideal to take the high interface loads while serving as a quick disconnect. The thruster is incorporated into the attachment structure, a new and outstanding feature of the separation system.

The pyro thruster concept shows these distinct advantages and is scheduled for further development. During the next four years, in Phase II of the ALS program, pyro thruster requirements will be finalized, preliminary design will be completed, and a prototype will be built and tested.

BOOSTER INSTALLATION

The booster is attached to the core in the vertical position. Booster installation is accomplished by using a handling yoke and an automated overhead crane, as shown in Figure 6. Attached to the yoke, the crane rotates and moves the booster out of the transporter using CAD-assisted computer control, verified by modern laser alignment technology for multi-axis automatic positioning. Continuous crane operation moves the booster into the mating position and aligns the ball races with their retainers at the three booster-core interfaces. After the races are lowered and seated, the retainer latches are activated and the ball races are captured (see Fig. 4). The retainers have tapered guiding surfaces for the races, to facilitate mating and to help relax the accuracy of the position control system.

The joints at the booster-core interfaces are designed to have liberal tolerances. Widening the manufacturing and alignment tolerances lowers cost and installation time, but causes a greater degree of booster-core misalignment, which in turn has an effect on flight control. This problem, however, can be solved by adding more power to the engines and widening their gimbal angles. This is a good example of the fundamental tendency in the ALS design philosophy of trading high performance for robustness.

High launch rate requires minimum installation time. Core-booster attachment hardware and positioning equipment must be robust, simple, and efficient. The core-booster integration operation must be automated to the highest practical and affordable degree.

During ALS Phase II, the requirements for booster handling, positioning, and installation will be finalized.

CONCLUDING REMARKS

Special attention and understanding are required to correctly interpret the relationship of robustness and redundancy in terms of reliability and safety, as applied to the ALS program. Explicit definitions, illustrated by examples that describe the meaning of this relatively new and difficult relationship, are needed to enrich and update the dictionary of technical terms. These definitions must then be tailored to ALS structural, mechanical, fluid, and electrical engineering applications. The definitions would be instrumental in guiding the design and failure mode analyses efforts.

Replacing high performance with robustness is a relatively new phenomenon in the modern aerospace business. To eliminate doubt and differing opinions during the design phase, mutual agreement on the interpretation of definitions is mandatory. In recent years, misdirection due to lack of unanimous interpretation of redundancy versus equivalent redundancy has led to disagreements. This resulted in design changes, impacting schedule and cost [1]. The technical term "equivalent redundancy" is being replaced by the more attractive word "robustness."

REFERENCES

1. Hornyak, Stephen: Inherent Problems in Designing Two-Failure-Tolerant Electromechanical Actuators. Proceedings of the 18th Aerospace Mechanism Symposium, May 1984, NASA Conference Publication 2311.

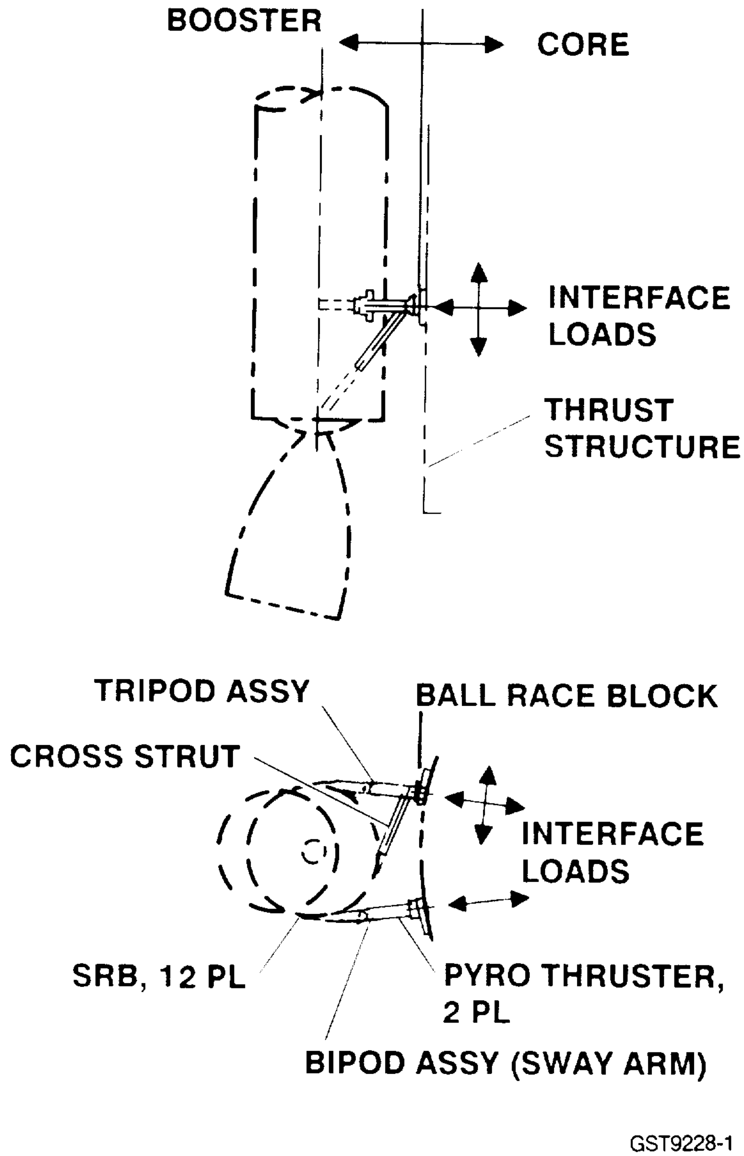


Figure 1. Aft attachment.

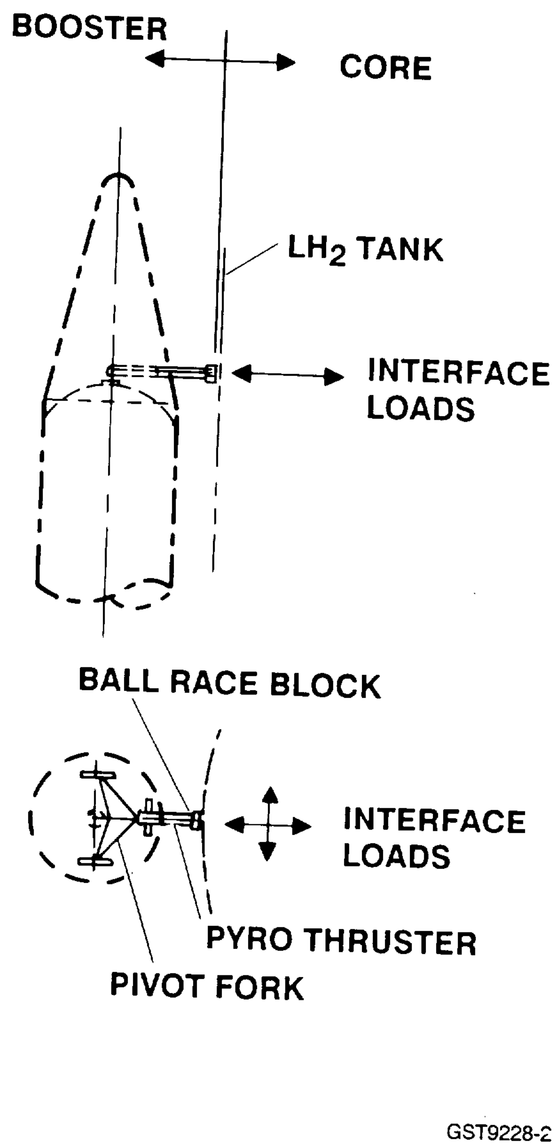


Figure 2. Forward attachment.

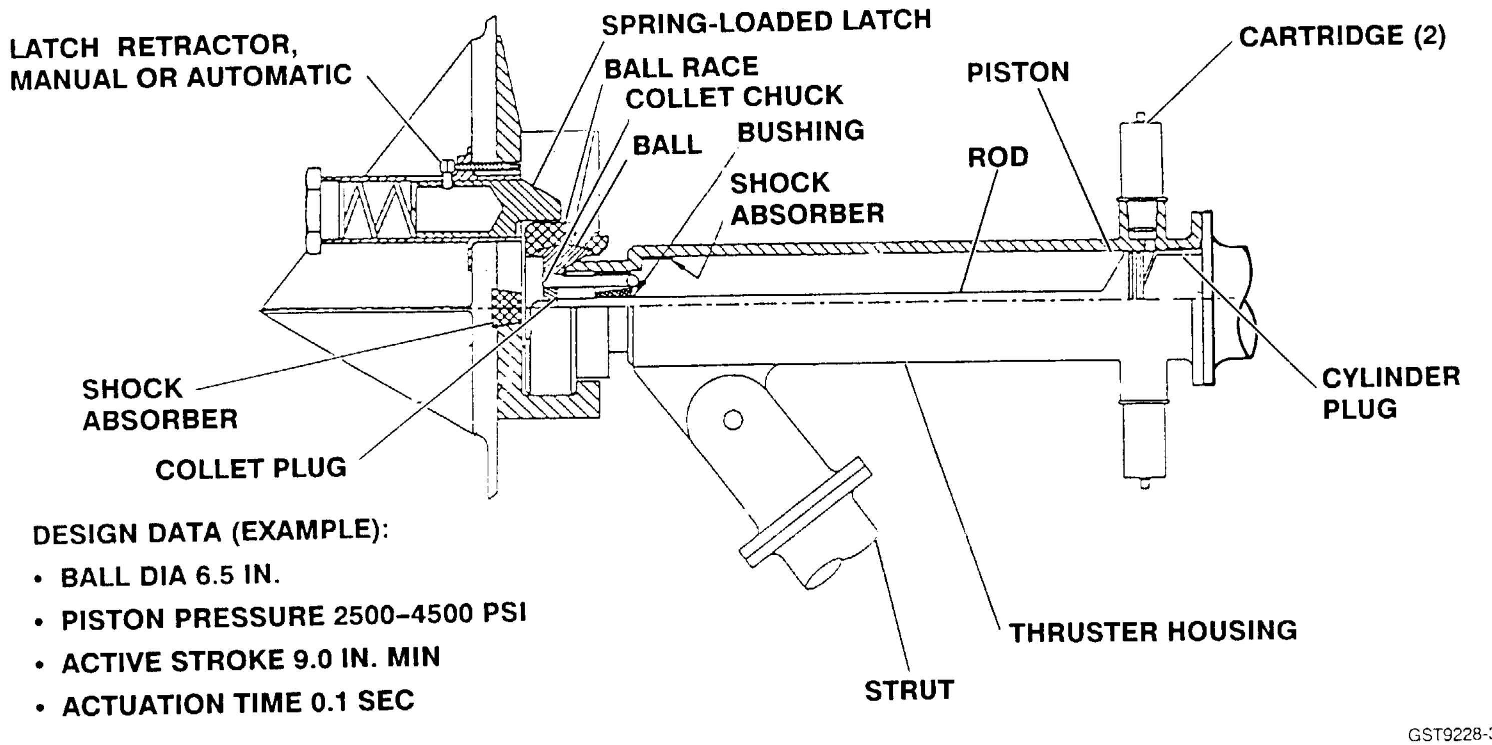


Figure 3. Pyro thruster quick disconnect (side view).

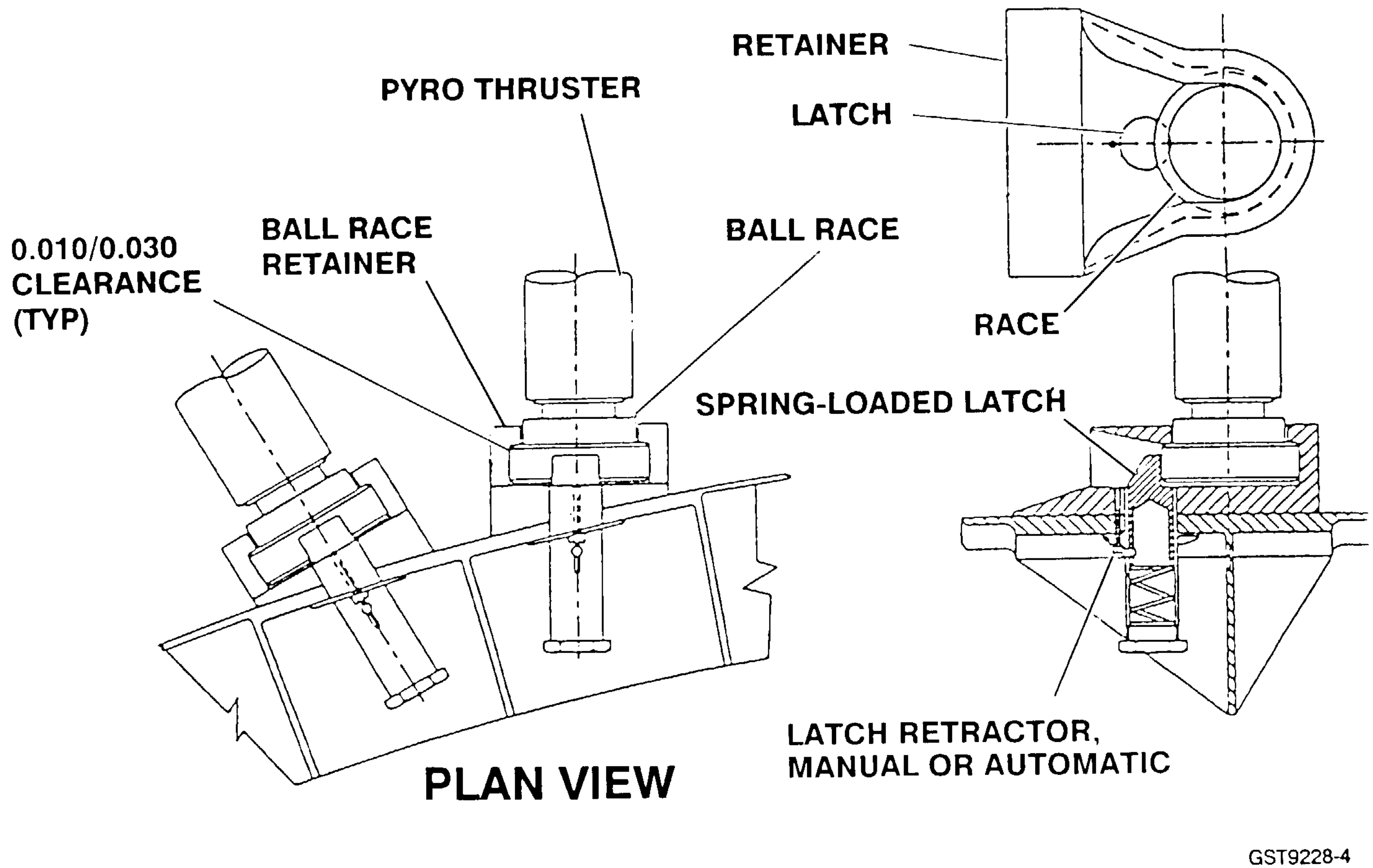
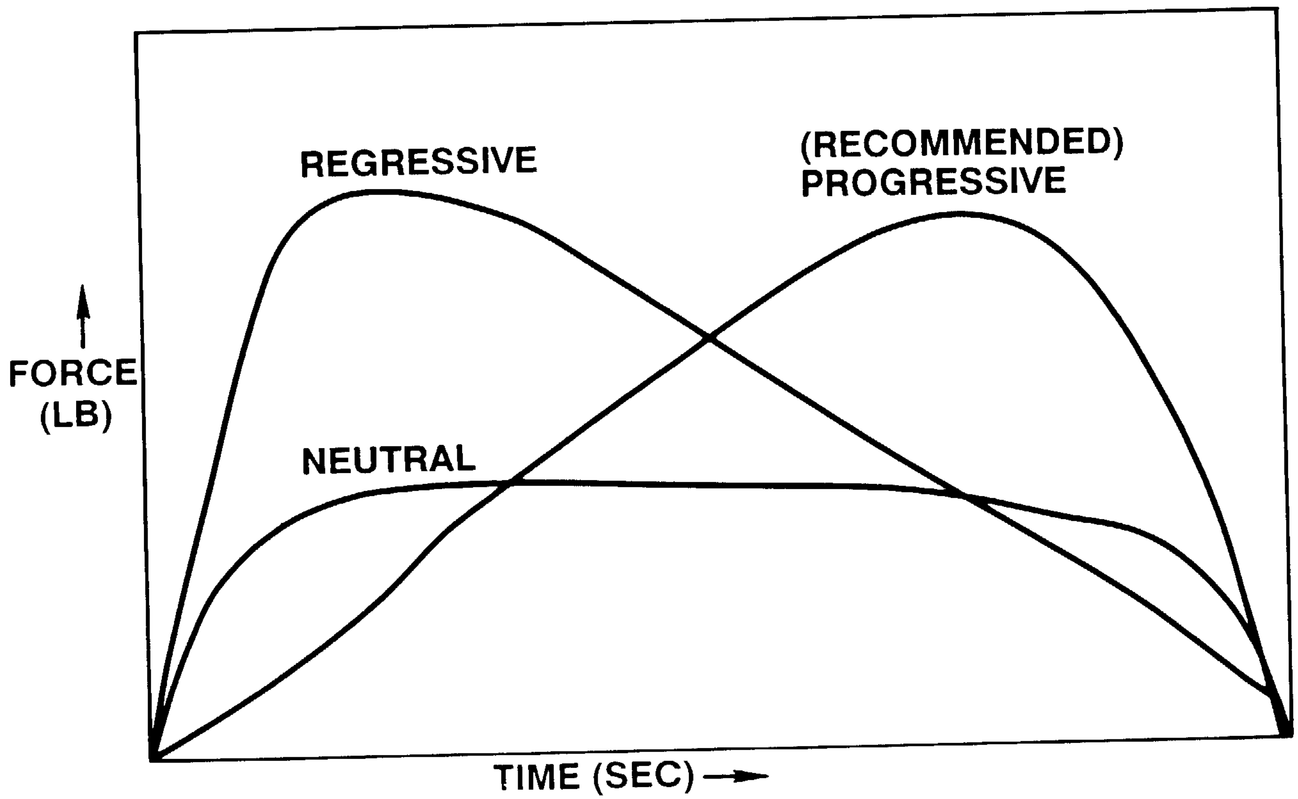


Figure 4. Automatic pyro thruster attachment.



PRESSURE AND FORCE VERSUS TIME ARE DEPENDENT UPON PROPELLANT GEOMETRY AND ARE THEREFORE TAILORABLE TO A CERTAIN EXTENT.

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Figure 5. Cartridge thrusting characteristics.

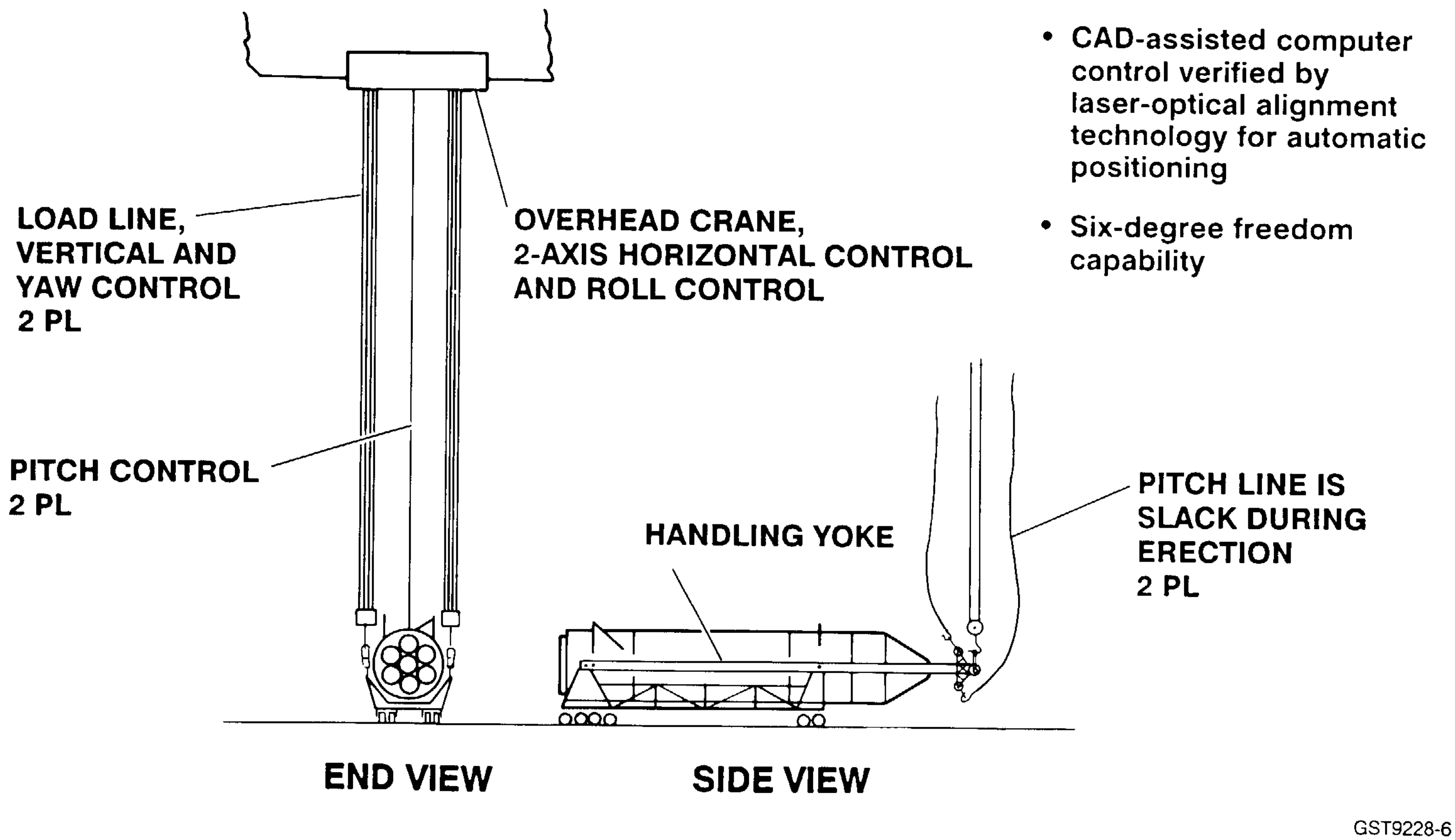

Figure 6. Automated handling and positioning concept for core, booster, or shroud.