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TRIDENT I THIRD STAGE MOTOR
SEPARATION SYSTEM

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INTRODUCTION

The TRIDENT I is a submarine launched, three stage ballistic missile with solid propellant motors (see Figure 1). The third stage of the TRIDENT I consists of a long, slender rocket motor mounted concentrically within the equipment section of the missile. Prior to the payload deployment phase of the mission, the third stage motor is jettisoned from the equipment section. The subject of this paper is the development of a system to disengage and separate the motor safely from the equipment section.

PRELIMINARY CONCEPTS

The third stage motor separation event was originally conceived to perform two functions - disposing of the motor and providing range control for the missile (i.e., terminating boost flight once the desired velocity has been achieved). With these objectives in mind, the two concepts depicted in Figure 2a and 2b were proposed. The first scheme, referred to as "Fly Through" involved pyrotechnically severing the third stage motor from the equipment section at a specified time during the motor burn. The thrust of the motor would then accelerate it through and away from the equipment section. A similar concept, dubbed "Thrust Reversal" consisted of cutting a large hole in the forward dome of the motor creating a net aftward thrust. Preliminary analyses showed that due to the large forces associated with a burning third stage motor, both of these schemes would require large, heavy guiding mechanisms to prevent severe impacts to the equipment section during separation. Additional drawbacks of "Fly Through" or "Thrust Reversal" include the severe gasdynamic/thermodynamic environment imposed upon the equipment section and the difficulty in conducting ground tests of either system.

FINAL SEPARATION SYSTEM DESIGN

The task of designing a third stage motor separation system was simplified when the range control requirement was dropped. An improved guidance and control system allowed the use of maneuvering techniques to achieve range control for the missile, thus freeing the separation system from this function. The body to be jettisoned then became a relatively light, burned out motorcase rather than an actively thrusting motor whose mass properties could be greatly different depending on the time at

which separation is commanded. The design which has evolved is illustrated in Figure 2c and consists primarily of:

- a pyrotechnic joint which disconnects the third stage motor from the equipment section
- a small rocket motor to eject the third stage motor aftward
- eight roller sets attached to the equipment section which guide the third stage motor during separation.

The heart of the pyrotechnic joint is a detonating cord encased in an aluminum sheath which expands rapidly, fracturing the pregrooved ring that connects the third stage motor to the equipment section. The pancake-shaped eject motor, mounted in a well in the forward dome of the third stage motor, is fired simultaneously with the pyrotechnic joint and produces approximately a "1g" acceleration for one second. During the separation, the departing motor is guided by rollers which are mounted to the equipment section and backed by leaf springs with a stiffness of approximately 200 lb/in. When the third stage motor is mated to the equipment section, each roller assembly is nominally deflected 0.25 in., creating a 50 lb preload. The separation components are illustrated in Figure 3.

ANALYSIS AND TESTING

The development of the separation system began with extensive analysis utilizing a computer math model. Comprehensive testing followed to confirm and to improve this model. After three years and eighteen system tests, the present separation system was finalized.

Testing of the separation system has been conducted from the component level to live, full-scale system tests. Testing of the three primary components can be summarized as follows:

- eject motor – static firings under various temperature and pressure conditions
- pyrotechnic joint – functional tests to refine the joint design and determine the appropriate grain size
- separation rollers:
 - load/deflection tests
 - strength tests to failure
 - roller/motorcase friction tests
 - salt spray environment tests

The first series of full-scale system tests (drop tests) did not include a live pyrotechnic joint and eject motor. Since the separation force is approximately 1g, the third stage motor was allowed to freefall from rest through a rigidly held equipment section (see Figure 4). A lateral load was applied to the third stage motor during these drop tests to simulate the net lateral force and moment which may result from such anomalies as a misaligned eject motor, c.g. offset of the third stage motor, etc. The preloads of the separation rollers were varied and rollers were "jammed" and axially

misaligned to simulate manufacturing extremes. Instrumentation in these tests included high speed motion picture cameras, linear potentiometers on the roller sets, and deflectometers to measure the clearance between the third stage motor and the envelope reserved for the equipment section and payload. Accelerometers were mounted on the third stage motor to detect impacts against the equipment section. From these tests, the dynamics of the separation event were evaluated under nominal and "worst expected" conditions.

The test series ended with two full scale tests using live ordnance and under zero-g conditions. These tests are referred to as the "live eject" tests and are illustrated in Figure 5. It should be noted that the beam structure attached to the equipment section is a test fixture and not real equipment section hardware. The scenario for this test can be outlined as follows:

- a complete third stage (third stage motor and equipment section) is suspended upside down at the top of a test tower
- the entire assembly is released creating a relative zero-g condition
- the pyrotechnic joint and eject motor are fired simultaneously during free fall
- the thrust of the eject motor essentially suspends the third stage motor in mid air as the equipment section falls past it
- upon completion of the separation, both bodies are caught by hydraulic cylinders.

Instrumentation for the live eject tests was similar to that employed for the drop tests, with additional accelerometers on the equipment section and high speed motion picture cameras mounted on board the equipment section to detect roll motion of the third stage motor with respect to the equipment section. Two live eject tests were conducted; the first one simulated a nominal separation and the second simulated a severe combination of parameters. Both tests functioned successfully.

After the math model was validated based on data from the system tests, it was used to assess the performance reliability of the third stage separation event. To do this, a mean and a standard deviation were assigned to each of the important parameters shown in Figure 6. A random number generator was then used to select input data sets from these normal distributions. After a large number of runs were made, various quantities of interest, such as peak roller loads, could be plotted as functions of their probability of occurrence.

CONCLUSIONS

The third stage motor separation system has shown through test and analysis that it can effectively and reliably perform its function. Additionally, the weight of the hardware associated with this system is well within the targeted value.

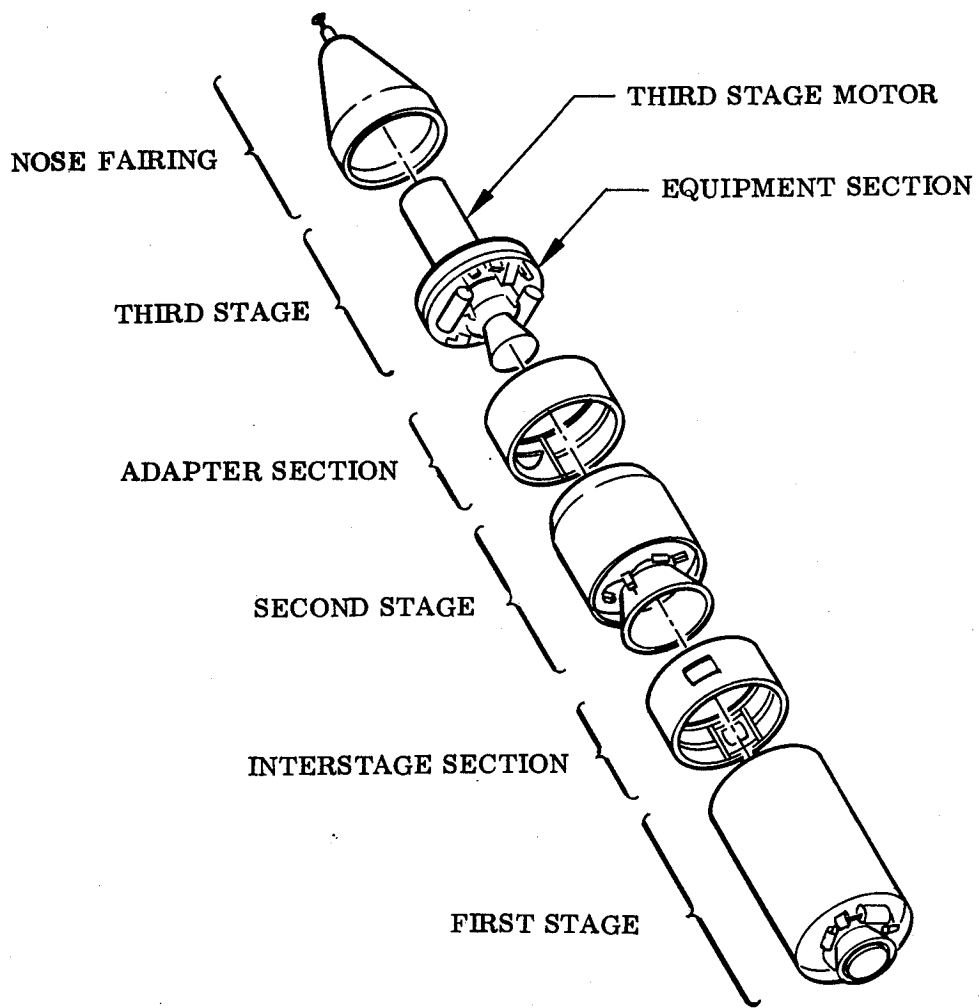
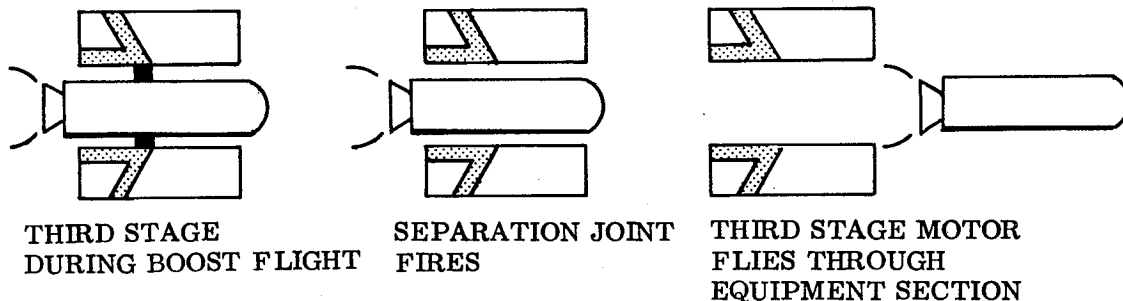
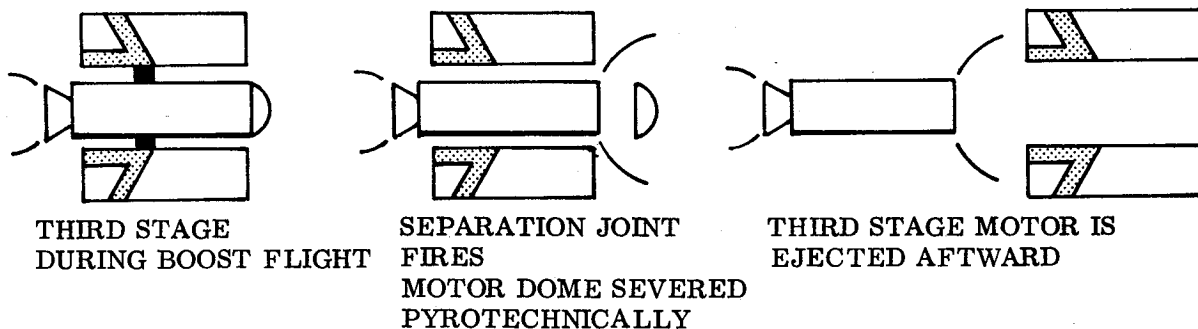


Figure 1 TRIDENT I Missile

(A) FLY THROUGH



(B) THRUST REVERSAL



(C) SOFT SEPARATION - FINAL DESIGN

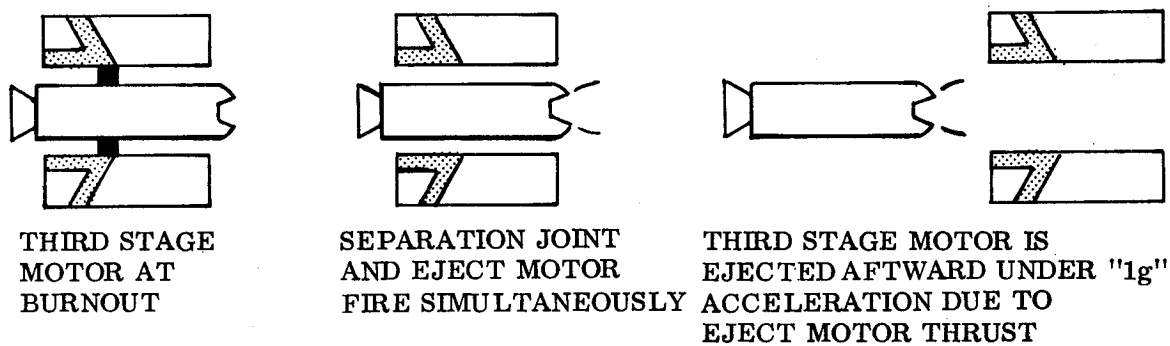


Figure 2 Separation Concepts

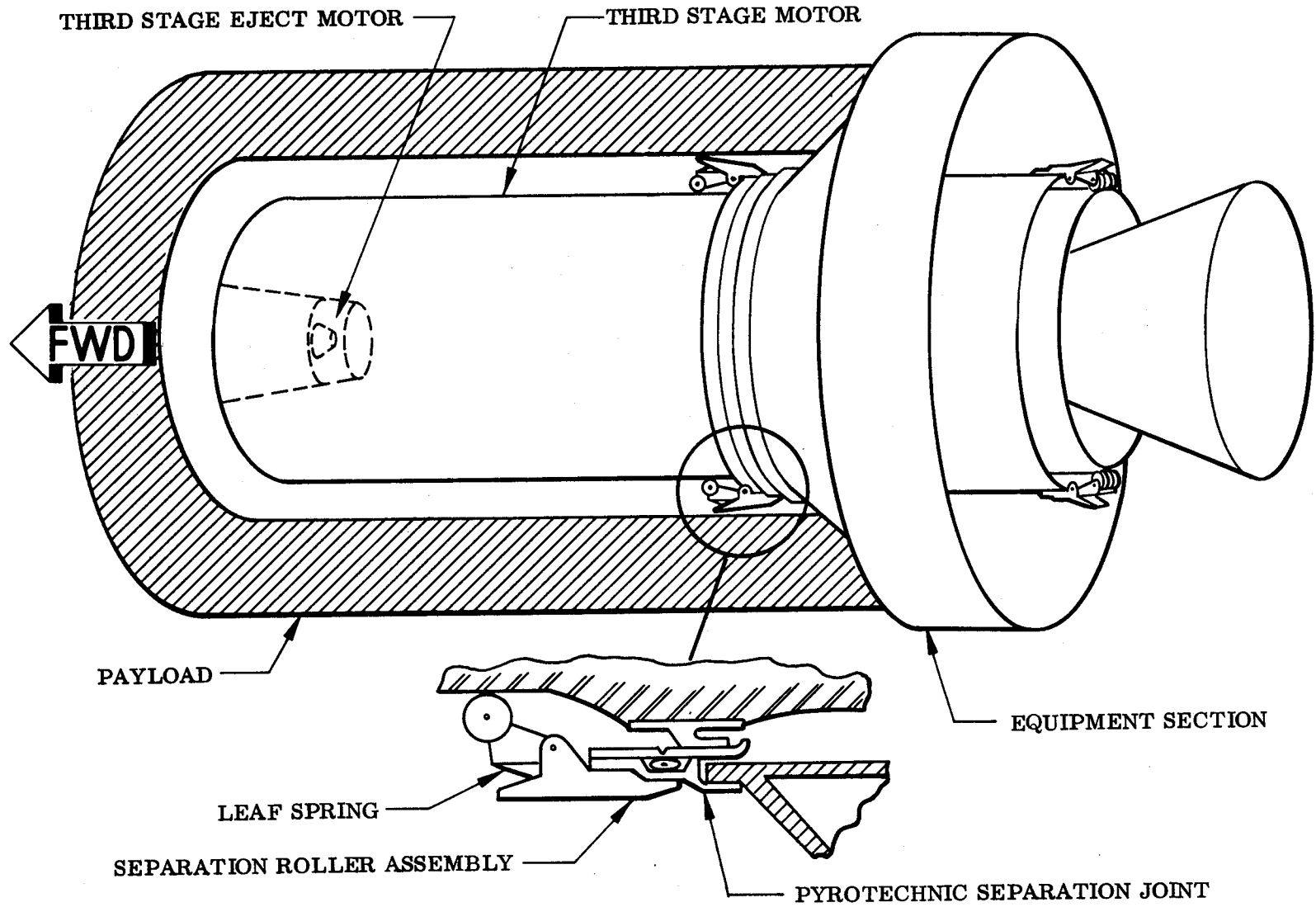


Figure 3 Components of the Third Stage Separation System

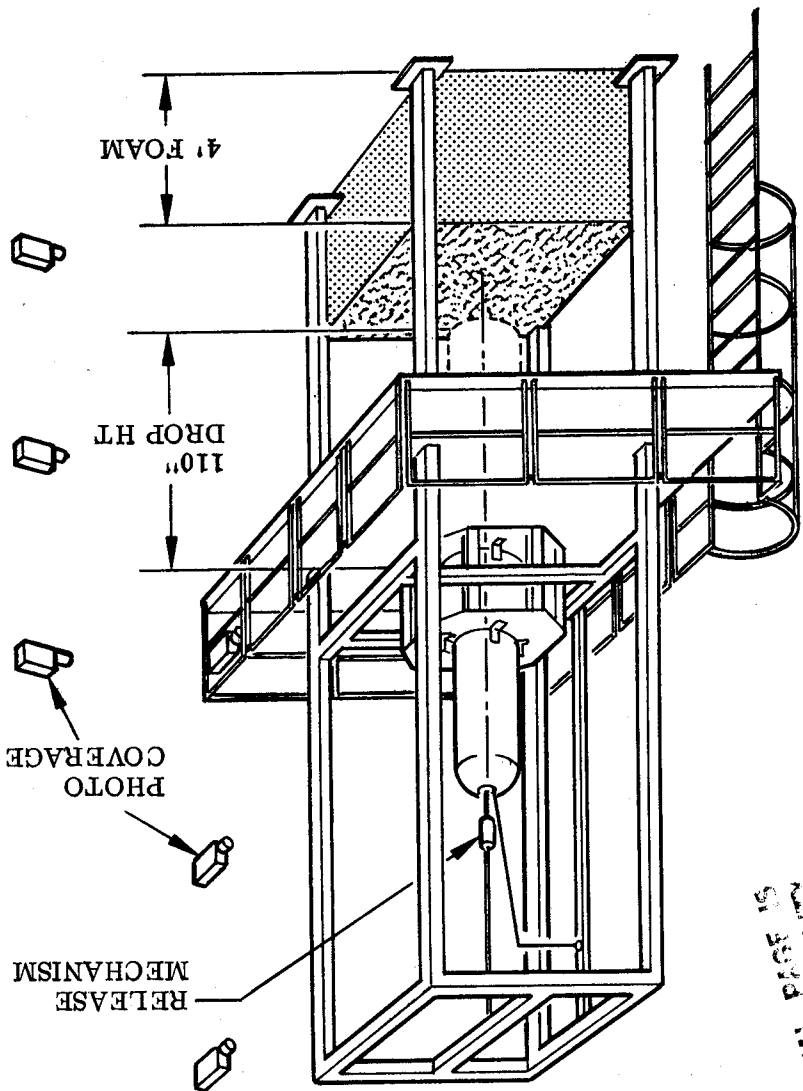
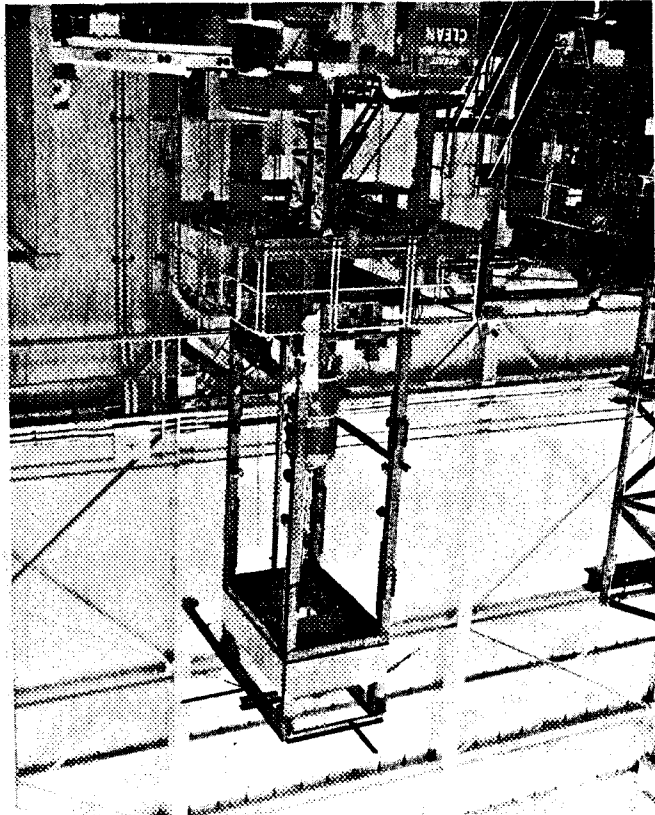


Figure 4 Drop Test



DROP TOWER

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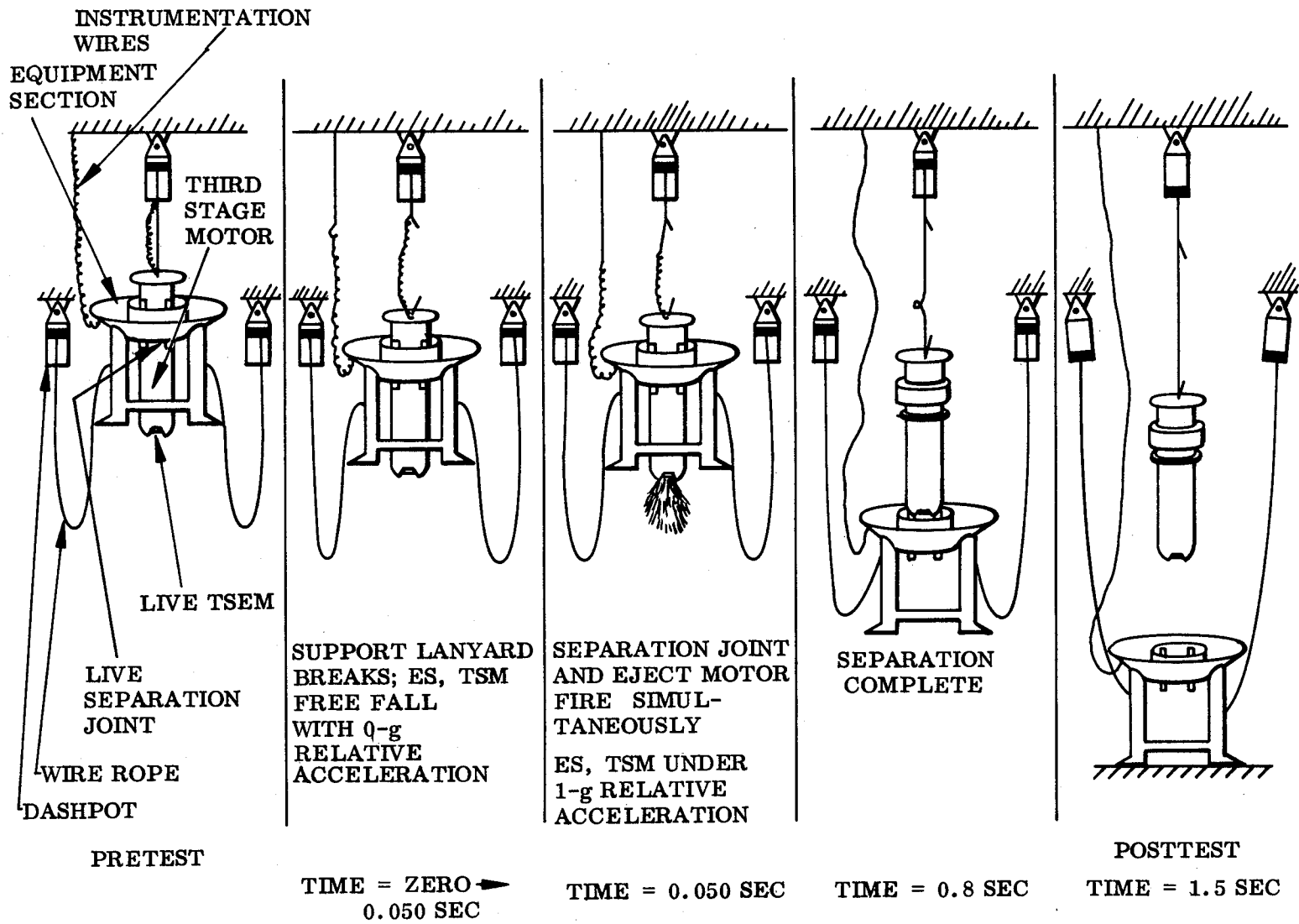


Figure 5 Live Eject Test

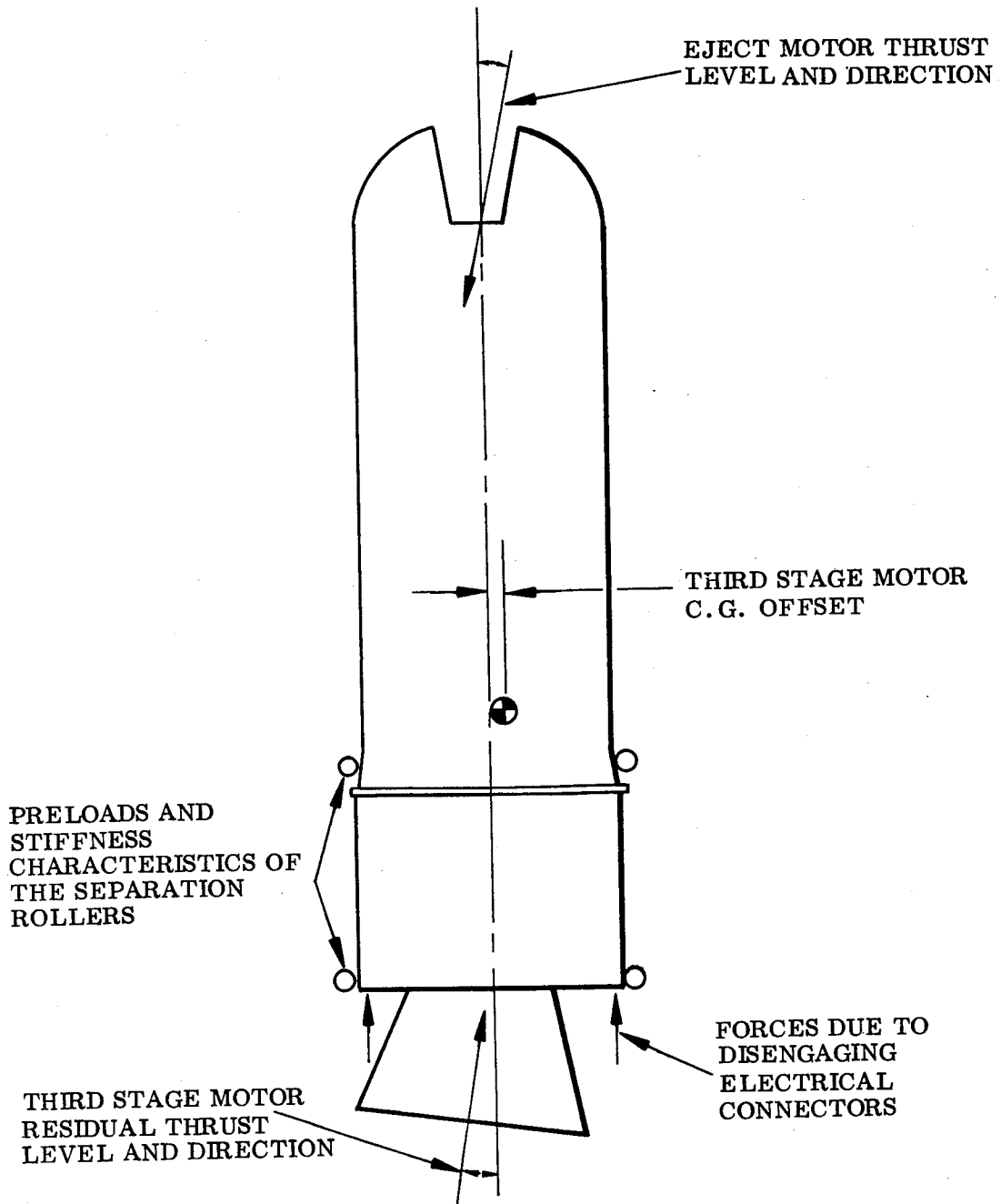


Figure 6 Important Parameters in the Analysis of the Third Stage Motor Separation Event

