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Abstract

Plume Diagnostics of the RSRM Static Firings for the Pressure Perturbation Studies

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During the STS-54 launch (RSRM-29), the right hand solid rocket motor experienced a 13.9 psi chamber pressure perturbation at 67 seconds into the motor operation (figure 1). This pressure augmentation equated to a thrust change of 51 klb. Concerns were raised regarding the adverse effects of this thrust imbalance on the shuttle system and the overall thrust into the external tank structural elements. Historically, several shuttle solid rocket motors flown to-date have exhibited pressure perturbations during the period 65 to 75 seconds into the motor burn time. However, all these variations, including the STS-54, have remained within the specification limits. Post flight assessment of the motors have not revealed any anomalous conditions.

Pressure perturbations have been observed in solid rocket motors due to expulsion of igniter or insulation materials and the motor thrust during

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such events drop abruptly before rising. However, the RSRM motors do not exhibit such behavior during the large chamber pressure perturbation events. Instead, the thrust is in phase with the chamber pressure during this event, with a resulting thrust/pressure (F/P) greater than 1.0.

Several scenarios were investigated to explain these pressure perturbations in the RSRM motors based on a fault tree developed after STS-54. Of these, the expulsion of the slag accumulated in the submerged nozzle region appeared to be the most plausible scenario to explain the observations. Slag is a natural combustion product of aluminized solid rocket motors. The RSRM propellant contains 16% by weight of aluminum. The cavity in the submerged portion of the nozzle in the aft-end of the motor provide an ideal location for accumulation of the slag during the motor burn. Any ejection of this slag mass during nozzle vectoring or other side loads on the motor will result in the chamber pressure perturbation.

Two RSRM static firings; Test Evaluation Motor (TEM-11) and Flight Simulation Motor (FSM-4) were instrumented extensively to further understand the slag expulsion phenomenon in the RSRM and the associated pressure perturbations. The instrumentation included non intrusive optical and infrared diagnostics of the plume such as high speed photography, radiometers and thermal image cameras. This article describes the optical and infrared instrumentation used in the two static firings, the observations from these instruments and the interpretations to support the slag expulsion during the pressure perturbations.

During the static firing, the motor is oriented horizontally with the centerline about 10 feet above the ground. This orientation provides a favorable attitude for accumulation of slag in the aft end of the motor which was indeed observed in the real time radiography (RTR) of the motors. Unique duty cycles, as shown in figure 2, were employed in the static firings to examine the possibility of inducing large chamber pressure perturbations during the nozzle vectoring events.

The motor plumes were visually observed using high speed cameras at 2000 frames/sec. The cameras were located about 300 feet from the nozzle and observed about 5 nozzle diameters long plume from the nozzle exit plane. Video images, as shown in figure 3, clearly demonstrate the expulsion of hot, bright material in the vicinity of the bottom of the nozzle exit plane during the chamber pressure perturbations. These ejections are highly localized and continuous during short intervals and are induced by vectoring the nozzle inlet lip toward the accumulated slag slurry in the aft end of the motor. Also, these ejections are correlated well with the large chamber pressure perturbations associated with the nozzle vectoring event

Figure 4 shows the radiometer arrangement employed in the static firings to support the pressure perturbation analysis. Wide angle radiometers were mounted directly on the nozzle wall and aimed parallel to the plume axis. These radiometers would provide a circumferential distribution of the plume radiation during the pressure perturbation events. 4-degree narrow view radiometers were also mounted on a post downstream of the nozzle exit plane to measure radiation across the plume. A typical radiometer result from TEM 11 test is illustrated in figure 5. The results of these radiometers clearly demonstrate the localized nature of the hot emissions in the plume during the nozzle vectoring and the associated chamber pressure perturbations.

Infrared cameras were also employed in the two tests to observe the plume in the 3-12 μm range at a scanning rate of 30 frames/second. The cameras were located about 300 feet from the nozzle and about 80 feet forward of the nozzle. The thermal images clearly illustrate the ejection of sheets of hot material in the plume near the bottom of the nozzle exit plane coinciding with the large chamber pressure perturbations and the other plume observations such as radiometers and high speed photography.

All these non intrusive optical and infrared plume observations strongly indicate the ejection of sheets of hot, bright material near the bottom of the nozzle during large pressure perturbation events in the RSRM static firings. The only material that exists inside the burning motor that could be ejected in the form of discrete continuous sheets is the slurried slag. Also, the RTR images showed intense activities of the accumulated slag mass in the aft end of the motor immediately prior to the large pressure perturbations.

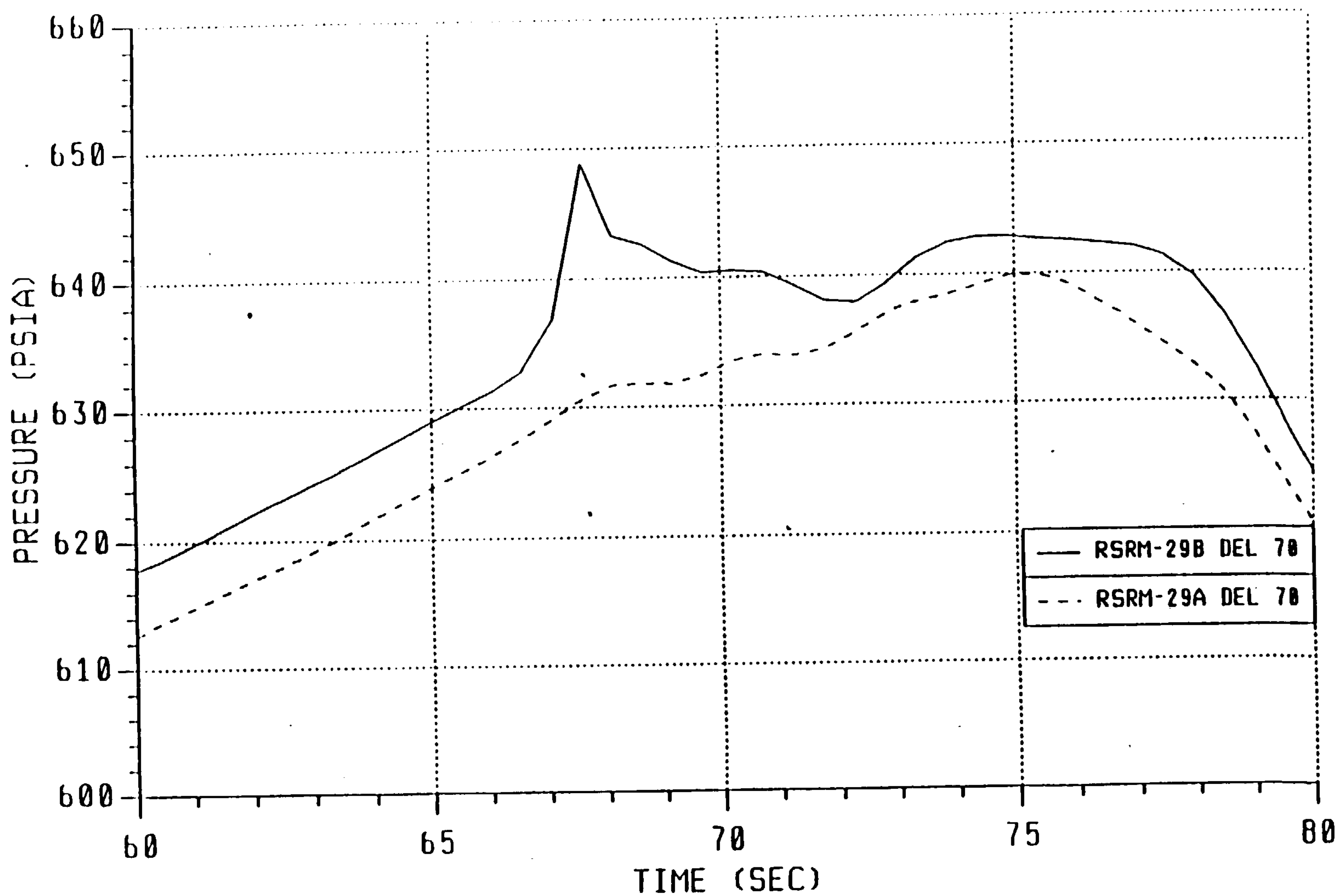

Figure 1. A 13.9 psi Chamber Pressure Perturbation Experienced by the Right Hand Redesigned Solid Rocket Motor (RSRM 29B) during STS-54 Launch.

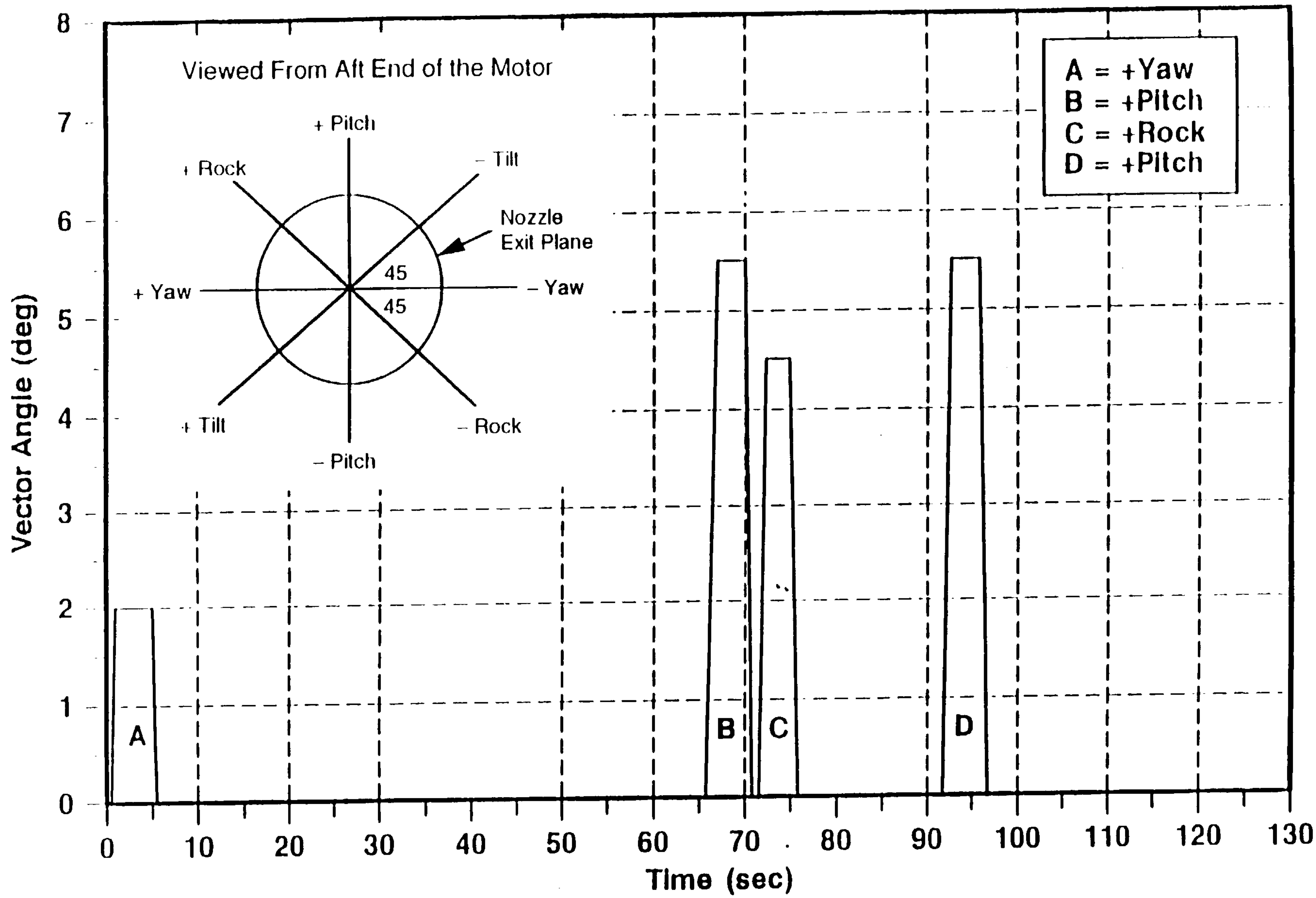

FIGURE 2.

An unique duty cycle was employed in the TEM-11 test to examine the possibility of inducing large chamber pressure perturbations during the nozzle vectoring events. The vectoring events B, C, and D are executed after 65 seconds to assure sufficient time for slag accumulation around the submerged nozzle. B and D are 5.5 degree pitch events and C is 4.5 degree rock event.

Figure 3. Ejection of Sheet of Hot, Bright Material at the Bottom of the Nozzle During the 11 psi Pressure Perturbation Event in TEM-1[illegible].

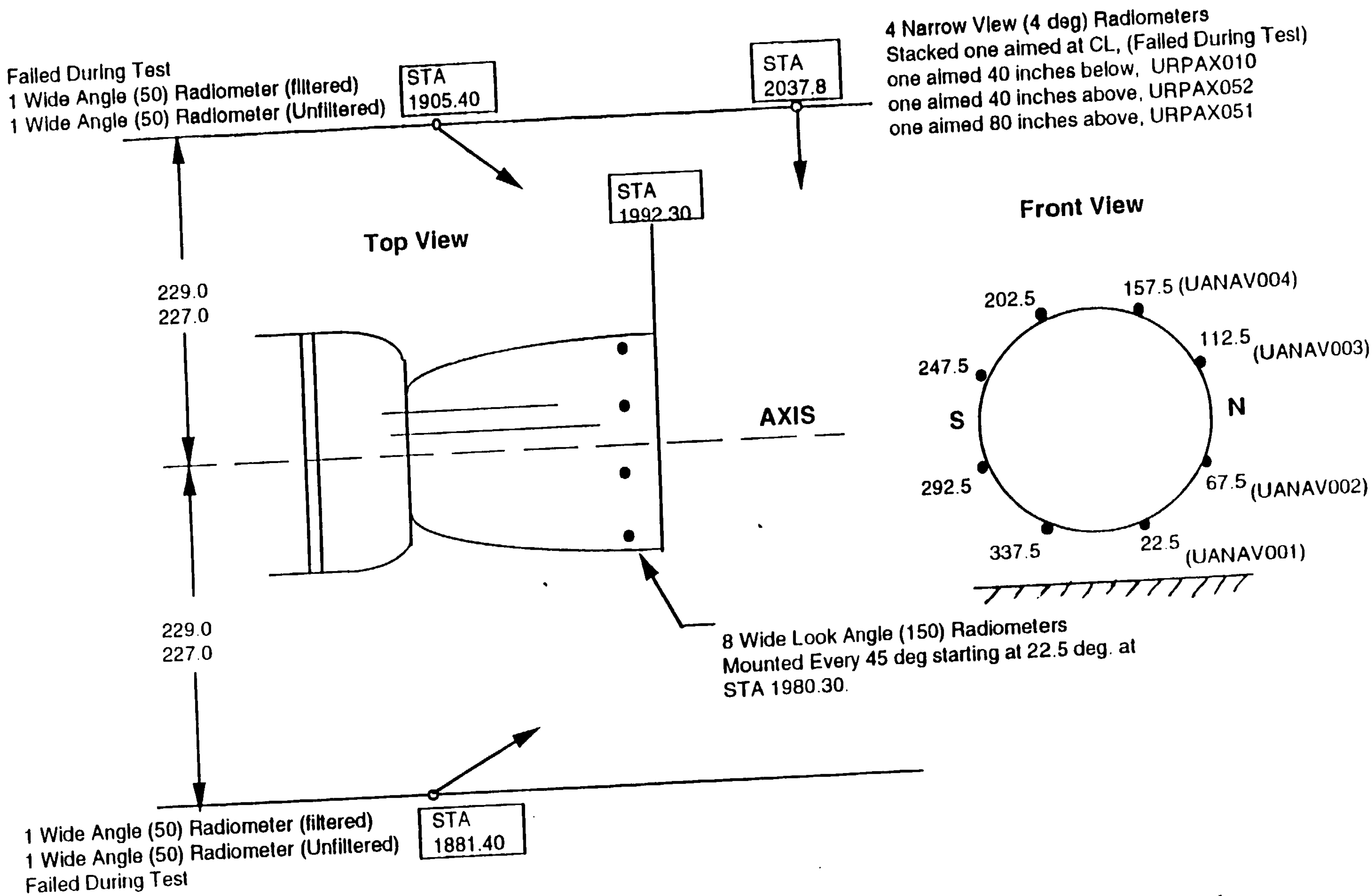

Figure 4. Radiometer Arrangement Employed in the Static Firing of the RSRM Motors to Support the the Pressure Perturbation Studies. The Motor Centerline is about 10 feet from the Test Bed Floor. the Nozzle Exit Plane Diameter is about 12.2 feet.

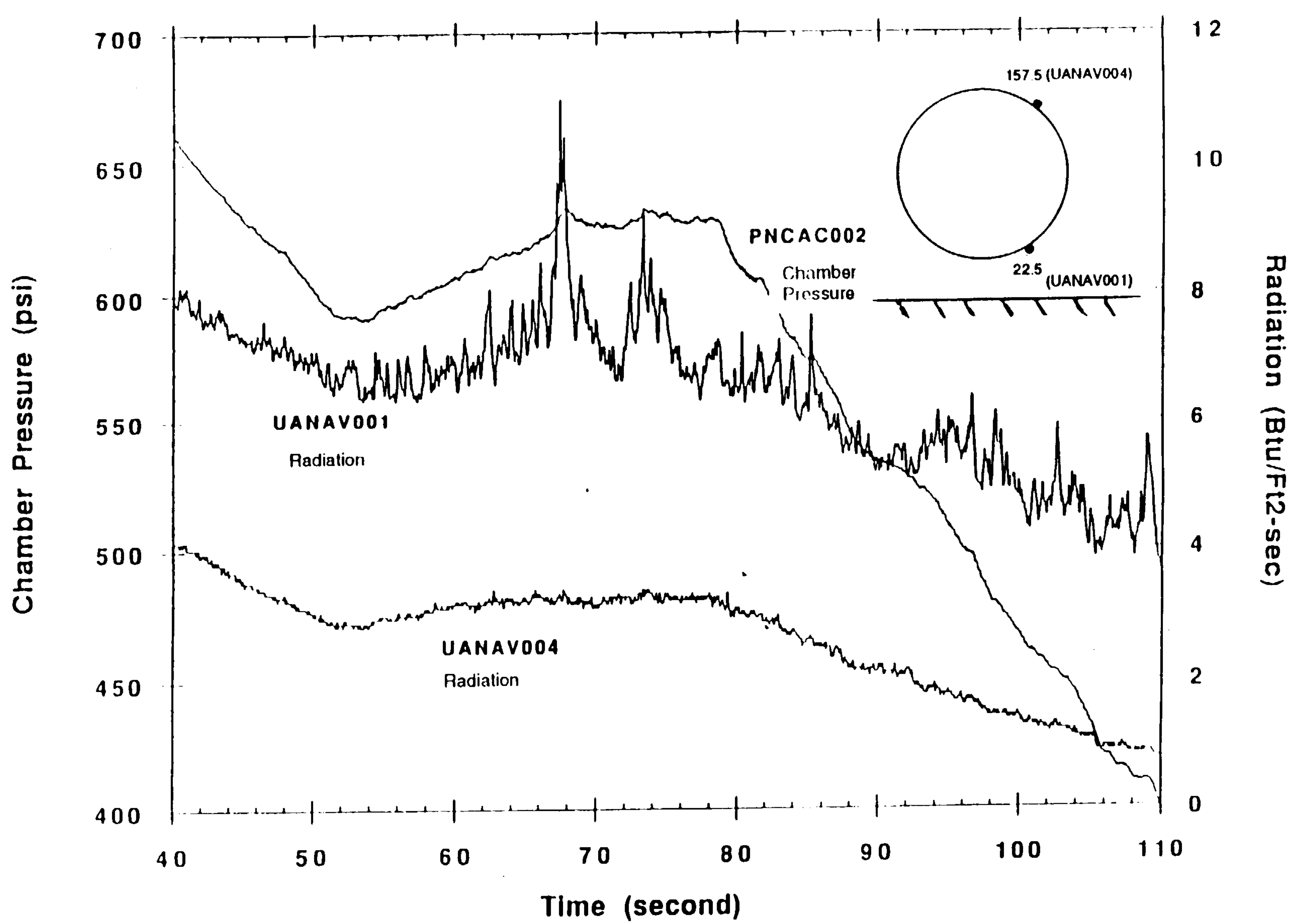

Figure 5. The One-to-one Correspondence Between the Large Pressure Perturbations in the Motor Chamber Pressure and the Radiation Spikes in the Radiometer (UANAV001) Mounted Near the Bottom of the Nozzle Exit Plane is Demonstrated. The Radiometer (UANAV004) Mounted Near the Top of the Nozzle is Absolutely Quiescent During the Pressure Perturbation Events.