

## Approach to the POGO stability analysis of a liquid-propellant “core and strap-on boosters” launch vehicle

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The “core and strap-on boosters” layout of launch vehicle (LV) stages is quite common in heavy LV development. However, POGO oscillations in liquid-propellant LVs with this stage layout have some features.

It is shown that the structure of LVs of this type as a dynamic object has a dense spectrum of natural frequencies and complex spatial mode shapes. The longitudinal oscillations of the identical elements of the LV side strap-on boosters may be in phase or in antiphase, while the longitudinal mode shapes of the LV central core and strap-on boosters may differ both in phase and in amplitude. In flight, the thrust of the engines of the side strap-on boosters may also oscillate in phase or in antiphase, as a result of which the interaction of the LV structure with the sustainer propulsion systems of the side strap-on boosters may have both a stabilizing and a destabilizing effect on the POGO stability of a liquid-propellant LV.

This paper presents a mathematical model of the “liquid-propellant propulsion systems – LV structure” dynamic system. The model describes the interaction of the longitudinal vibrations of the structure of a two-stage “core and strap-on boosters” LV with the core and strap-on booster propulsion systems. The free longitudinal vibrations of the structure of a ‘core and strap-on boosters’ LV were simulated using computer-aided finite element design tools (CAE systems). The simulation was the first to account for the dissipation of the liquid propellant and LV structure oscillation energy.

The paper suggests an approach to analyzing the POGO stability of liquid-propellant “core and strap-on boosters” LVs with the use of the Nyquist criterion generalized to the case of multidimensional dynamic systems. The approach is based on opening the thrust feedback loops of the “liquid-propellant propulsion systems – structure” closed-loop dynamic system and studying the stability of the one-channel systems obtained in this way. Based on the proposed approach, the interaction between the longitudinal vibrations of the “core and strap-on boosters” LV structure and low-frequency processes in the liquid-propellant sustainer propulsion systems of the LV first stage was studied numerically.

**Keywords:** *POGO stability of liquid-propellant launch vehicle, liquid-propellant rocket engine, multiloop system, generalized Nyquist criterion, oscillation frequencies, logarithmic oscillation decrements.*

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