Second crisis of Starship program

Yu. I. Lobanovsky

Summary

This paper shows that failures of Starship second stage – Ship Block 2 in the last two flights occurred for two different reasons. In the seventh flight, this happened due to the occurrence of transverse fluctuations of new design pipelines for feeding methane to the external engines with vacuum nozzles, and in the eighth – due to the occurrence of longitudinal auto-oscillations of Pogo-type with hydroacoustic fluctuations in the oxygen feeding lines.

It follows from analysis that the very first attempt to change the design of Starship completely devalued all the achievements of SpaceX Company obtained during overcoming of first crisis in the test program associated with various Pogo options plaguing this rocket system. This happened because the previous methods of its suppression at the new stage of the program became practically inapplicable, and also because it was impossible to predict before flight where, when and why a new auto-oscillatory process would arise and whether it would arise at all this time. This is the main content of the second, and, apparently, the deepest crisis of Starship program. Without a full-fledged theory of Pogo due to the desire of the company's management to hide the very fact of special susceptibility of this rocket system to longitudinal auto-oscillations, SpaceX company will be forced to fight for a long time and blindly with the suddenly emerging more and more new auto-oscillatory processes of this type with each change in Starship design.

Keywords*: Starship, Pogo, longitudinal auto-oscillations, transverse oscillations, frequency, resonance*

I. Introduction

Main result of first four flights under Starship system test program was that both of its stages: first – Super Heavy booster, and second – Ship were able to successfully complete all active maneuvers using their main power plants and make soft splashdowns on the ocean surface. During this time, five similar critical problems that arose in flight were overcome, which first led to detonation of the rocket system, then to a trajectory failure, and in three cases – to explosions of its stages in flight. This allows us to single out the first four launches of the system as a first stage of its testing, during which the assigned priority tasks were accomplished.

The cause of all these problems was the occurrence of different options of Pogo type longitudinal auto-oscillations. After the first flight, Pogo process was eliminated by introducing an intermediate interstage compartment that has changed the frequency of Starship hull own oscillations, which prevented the excitation of auto-oscillations in this phase of the flight. In flights, starting with the third, SpaceX (the developer of Starship) used the following standard algorithm to solve Pogo problems: receiving telemetry data on the emergency process during the flight, and changing the engine operating mode during the next start so that the frequency of hydroacoustic oscillations in the fuel system of the power plant, the second component of this auto-oscillation process, leaves the Pogo zone. Then the flight is either successfully completed or continues until the next accident, with repeating these actions until all these incidents stop. The required change in the engine operating mode was determined based on a formula that linked it to the frequency of hydroacoustic oscillations. SpaceX gained access to this formula between the second and third flights of Starship, in November 2023 – January 2024. All this, as the results of the first phase of testing, was presented by the author at the end of January 2025 in a report at XLIX Academic Readings on Cosmonautics. A summary of this speech is presented in work [1].

During Starship fifth and sixth flights, other problems were solved, mainly related to the return of booster to the launch complex and its capture there during landing by its side consoles, as well as with heat protection of Ship during descent from orbit. Booster was successfully captured on the first attempt, and modification of heat protection threatens to drag on for an indefinite period already on new versions of this rocket system. However, neither one nor the other is included in the range of problems considered in this work. As for Pogo, it can be noted that in the fifth flight, during boostback – manoeuvre of returning the booster to the launch complex, for the first time, departure in the hydroacoustic oscillations frequency from the Pogo zone was achieved not by throttling, but by forcing the engines in relation to the mode that was initially used (and which led to the explosion of the booster in the second flight). The same began to be done in subsequent flights.

Since a payload mass of Starship Block 1 first version, especially given the thrust limitations of the engines due to Pogo, turned out to be very close to 0, the seventh launch began testing the system with an increased launch mass. The second version of Starship Block 2 consists of the same booster and a second stage extended by 1.8 m with significantly larger fuel tanks due to payload compartment [2]. The fuel mass increased by 300 tons, which should have allowed the launch of a payload of at least 20 tons in the form of 10 mock-ups of V3 Starlink satellites [3]. In January and March 2025, 2 launches of the second version of Starship were carried out. And they, quite unexpectedly, both for SpaceX and for media, which constantly followed these tests, ended with two explosions of the second stages. Unlike in the past, SpaceX and its chief engineer E. Musk, more than three and a half weeks after the test, haven't said anything about even the probable reasons for the latest fiasco, or when the next test launch can be expected.

Author decided, for the first time after the third flight, to describe in the current time mode the reasons for the last two unsuccessful tests, but in the texts he wrote for public access, for reasons clear, for example, from papers [1, 4], there will now be no specific data on the expected quantitative characteristics of newly identified emergency processes.

II. Trajectory data from last three Starship flights

Let us first consider the trajectory data for the last three Starship flights: the sixth flight (IFT-6) was performed with the first version of the system, and the seventh (IFT-7) and eighth (IFT-8) – with a more massive version of second stage (Ship Block 2). We will consider data only for second stages, since the first stages during these launches, not counting possible minor improvements, were practically identical, and if they have some problems during these flights, they were purely technical in nature, and, as a rule, were quickly and successfully resolved later. In the sixth flight, due to minor problems with the launch and landing equipment, the booster had to be sunk in the Gulf of Mexico [5], but the next capture of the booster was carried out smoothly. And in the eighth flight, 2 of the 10 engines of the inner ring didn’t turn on during the boostback, and one of them also didn’t turn on during the final braking [6], but this didn’t prevent B15 booster from successfully completing its flight.

Fig. 1 shows the flight speeds (in km/h) depending on the time (in seconds) of the second stages (including those in stack): the blue curve – for the sixth launch, the light brown curve – for the seventh launch, and the green curve – for eighth launch [7].

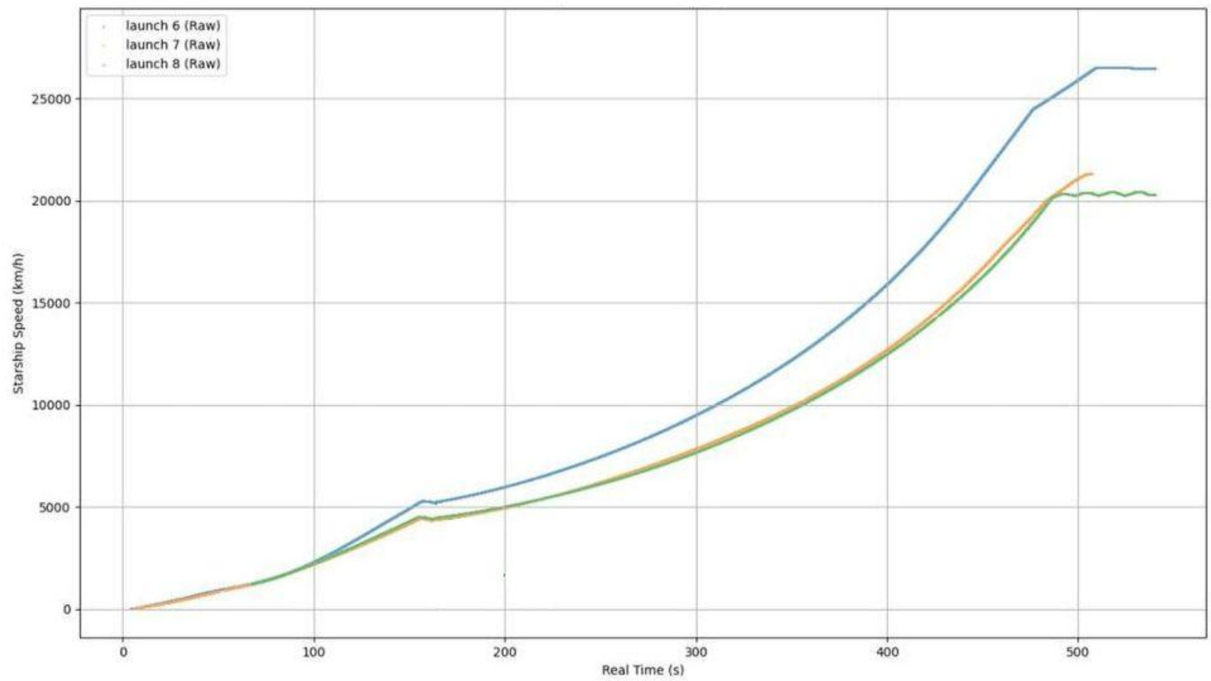

Fig. 1 – Ship speed in the last three flights (IFT-6 – IFT-8)

Due to its greater mass and the same power plant, new version of Ship accelerated more slowly than the old one. On the eighth flight, at least in the final phase of acceleration, the power plant thrust was slightly reduced compared to the thrust of the previous flight, but in both cases flights ended with the destruction of the second stages.

Accelerations (in fractions of the free-fall acceleration g) of these three second stages, the first stage in the eighth flight and the number of engines operating in that flight are shown in Fig. 2 [8]. As usual, when examining such graphs, it should be remembered that during a boostback, the direction of flight of the first stage changes to the opposite, and the accelerations that are shown as negative on graphs of this kind are actually positive (pressing the fuel to the bottoms of the tanks).

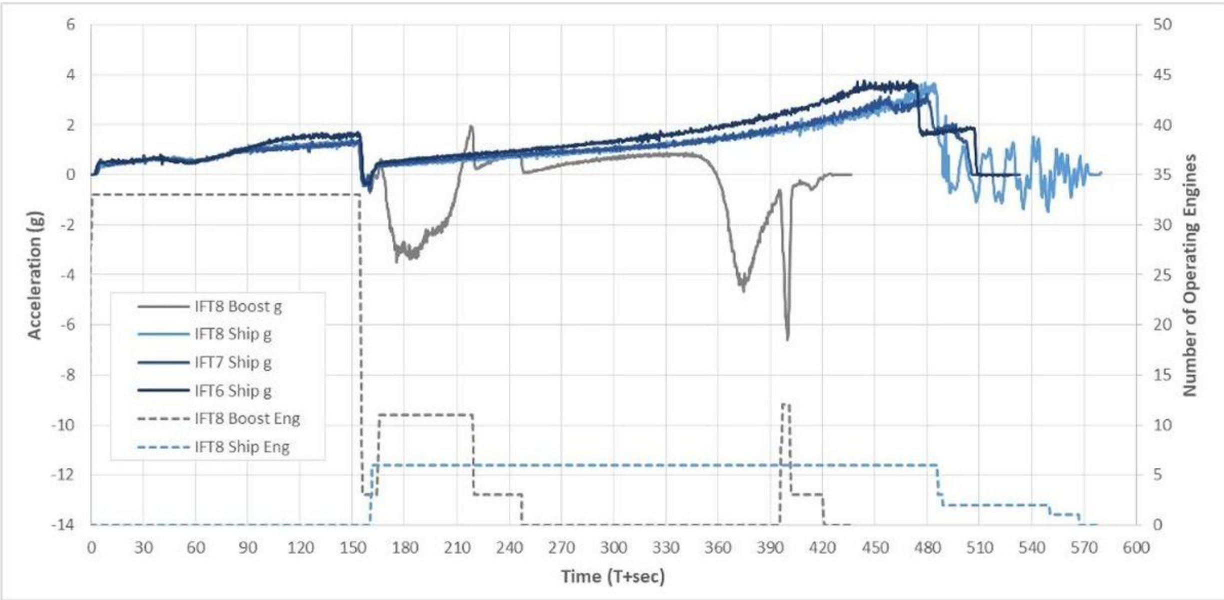

Fig. 2 – Starship system accelerations in the last three flights (IFT-6 – IFT-8), as well as booster acceleration and the number of operating engines in the eighth flight (IFT-8)

Fig. 3 shows in more detail the accelerations (also in fractions of g) in the final sections of the second stage acceleration in the seventh and eighth flights, which are key for understanding what happened [7]. Field of points received from the frames of the speed readings in video [9] after smoothing the data was displayed in the form of two relatively smooth curves presented here.

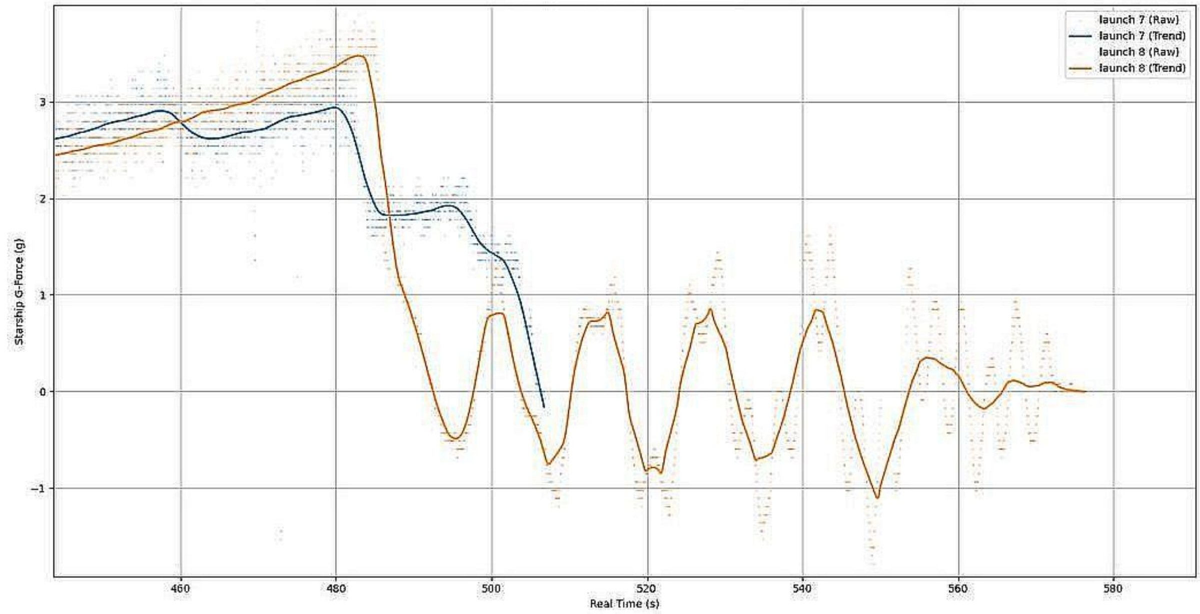

Fig. 3 – Accelerations of the second stages (Ships) during the final sections of the last two flights (IFT-7 and IFT-8)

Let us now return to Fig. 1, 2. The second stage acceleration in the sixth flight was traditionally completed by switching off three external Raptor-2 engines with vacuum nozzles, specially designed for operation in these conditions, 15 – 30 seconds before reaching the required speed. This was due to the fact that a little later in time they would enter pogo excitation zone. At the same time, a kink appeared on the speed graph, and potential payload was reduced, but in these launches, unlike the second, seventh and eighth flights, there was no explosions at the finish of the acceleration section. Moreover, with each flight from the third to the sixth, the time for switching off the external engines increased.

III. Architecture of engines fuel feedlines installed on two versions of Ship

In the author's first works [10, 11] on the assessment of causes of this Pogo variant, it was expected that hydroacoustic oscillations arose in the oxygen feedlines of Raptor-2 external engines, since it was assumed that their methane feedlines were so long that the possible oscillation frequencies in them couldn't be matched with the own frequencies of the elastic vibrations of the second stage hull. It should be noted that at that time the author didn't know not only the lengths of the pipelines, but also how they were laid. Only immediately before the seventh launch did these data, at least approximate, become known [12].

And then it turned out that the methane supply to all six engines was carried out with the help of one pipe running along the central axis of the oxygen tank, and already at the very end of this single pipe there were 3 side branches to the engines with vacuum nozzles, and just below there were 3 branches to the central engines with short atmospheric nozzles, see the left image in Fig. 4 [12]. And this, as the author was well aware from the experience of assessing hydroacoustic frequencies in penstocks of hydroelectric power plants, radically changed the whole matter.

Fig. 4 – Architecture of methane feedlines of Ship's first and second versions

Quite often at hydroelectric power plants, water is supplied from a reservoir to each turbine via a separate penstock, which is usually the case at HPP with concrete dams, through the body of which these channels pass. However, when dams are made of rock and earth, or when HPP machine rooms are significantly removed from the dams, which happens in the mountains, it turns out to be more efficient to first build long common tunnels for water, which only then branch out into separate penstocks to each turbine, that makes their schemes quite similar to what can be seen on the left in Fig. 4.

An example is Nurek HPP on Vakhsh River in Tajikistan, which experienced auto-oscillations in its penstocks, and 26 years before Sayan disaster, a similar incident occurred, but fortunately on a smaller scale [13]. In Fig. 5, you can see a diagram of main facilities and structures of this hydroelectric power station [14]. The central spot of complex shape is a rock-and-earth dam 300 meters high, which until 2013 made it the highest in the world. Of the many positions shown in Fig. 5, we are interested in only a few: position 7 is machine room of the station with nine turbines, position 11 is water intakes of three tunnels for water, and position 9 is the branching of each tunnel into three penstocks, approximately three times smaller in cross-sectional area, supplying water to each turbine. Positions 12 and 13 aren't worth paying attention to, as they are images of a temporary tunnel that allowed three turbines to operate during final phase of the station's construction. This tunnel was then closed.

Numerical experiments have shown that correct data on the frequencies of hydroacoustic oscillations (all 9 penstocks had different lengths there) are obtained if the lengths of the oscillatory circuits from their inputs to the turbines are taken to be only the lengths of these penstocks. In this case, the lengths of the preceding tunnels didn't affect the frequencies in any way. And this has always been the case in all branched pressure systems.

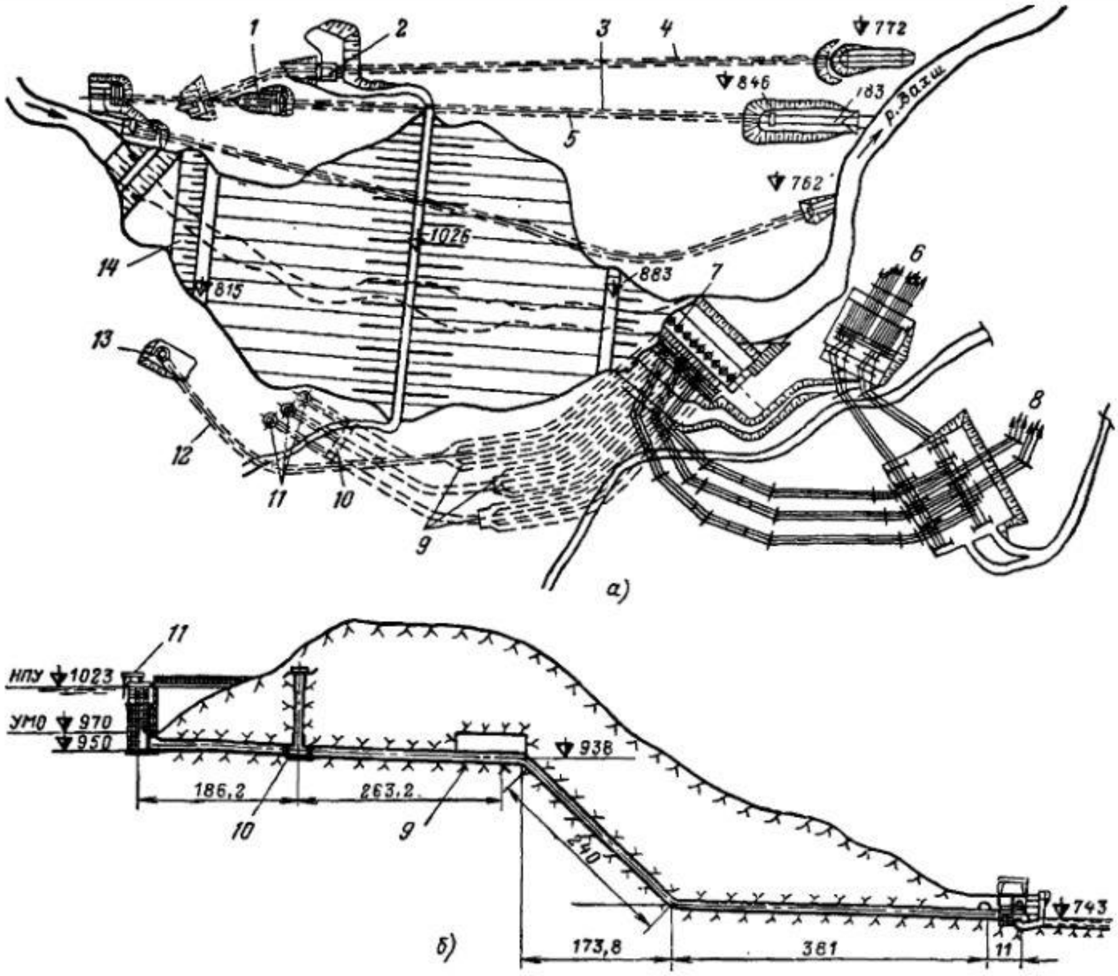

Fig. 5 – Scheme of the main objects and structures of Nurek HPP

A simple conclusion follows from this that the frequency of hydroacoustic oscillations of methane feedlines of the second stage outer engines was in no way related to the distance of methane tank from them and it was much higher than obtained in the first calculations, which assumed the use of a feed system without branches. And then it became known [15] that in the second version of Ship Block 2, SpaceX actually switched to exactly this scheme with direct feeding of Raptor-2 outer engines using separate methane pipelines, see the right part of Fig. 4 (the third pipeline isn't visible because of the remaining, as before, thick central pipe, through which methane is supplied to 3 central engines with atmospheric nozzles). Obviously, in such a configuration, outer engines couldn't excite Pogo, unlike with Ship Block 1 situation. The branches of the methane pipelines to the central engines were even shorter, and frequency of their hydroacoustic oscillations was even higher than that of outer engines, which also took them out of Pogo zone.

IV. Causes of Starship accident in the seven flight

After what was set out in the previous sections of this work, background of methane fuel system modernization of the second stage external engines, that is, the only qualitative change in its design, becomes completely obvious. At the final phase of second stage acceleration during the second flight, auto-oscillations of Pogo type has arisen in the methane fuel system of at least one of these engines, and from the third to the sixth flights, the external engines began to be turned off shortly before the excitation of this process, and the further, the longer they didn't work. Apparently, this was due to the gradual increase in the mass of second stage and the corresponding decrease in the frequency of elastic oscillations of its hull. However, all this could only be a temporary measure, since it reduced payload of the rocket system, and also didn't allow these engines to be used exactly where they were supposed to work. In this case, there is no need to talk about any orbital manoeuvres. In addition, on new second stage, due to the significant increase in its launch mass, frequency of own elastic oscillations of the structure should have been reduced much more significantly than in the last flights of the Block 1 version, and then preventing the excitation of Pogo could have led to an even longer flight of stage on only three central engines.

Since SpaceX doesn't have full access to the theory of pogo-type oscillations, and therefore doesn't have a clear idea of what to do when the geometry of the engine power supply system changes (in contrast to the very successful application of one of consequences from this theory on engine control with a fixed geometry of feeding system), the company decided to solve the problem in the simplest way. In principle, under conditions of time shortage, this was justified and quite logical.

They decided that if in the internal engines of second stage with practically straight pipelines there wasn't Pogo excitation, then methane pipelines of the external engines should be made equally straight and long. That is, they came to the use of the principle of homeopathy – "like cures like" (similia similibus curantur). Although, one must assume, they still don't know that the frequency of hydroacoustic oscillations in the central engines' feeding systems is apparently determined by the length of only short branches from the central methane pipeline, and not its full length. Nevertheless, even for such line with full length from the bottom of the methane tank to the external engines, as calculations show, nothing like Pogo occurs. And after ground tests of the new supply system, on January 16, 2025, Starship was launched with a new second stage, which, however, exploded at the end of acceleration, as in the second flight.

Let us now quote excerpts from the public report of SpaceX [16] on the results of the seventh flight: "After vehicle separation, Starship's six second stage Raptor engines powered the vehicle along its expected trajectory. Approximately two minutes into its burn, a flash was observed in the aft section of the vehicle near one of the Raptor vacuum engines [More precisely, after ~140 seconds (at 4:58), if we connect it with the closest superspike (a pair of downward-upward peaks on the graph) in Fig. 6]. This aft section, commonly referred to as the attic, is an unpressurized area between the bottom of the liquid oxygen tank and the aft heatshield. Sensors in the attic detected a pressure rise indicative of a leak after the flash was seen".

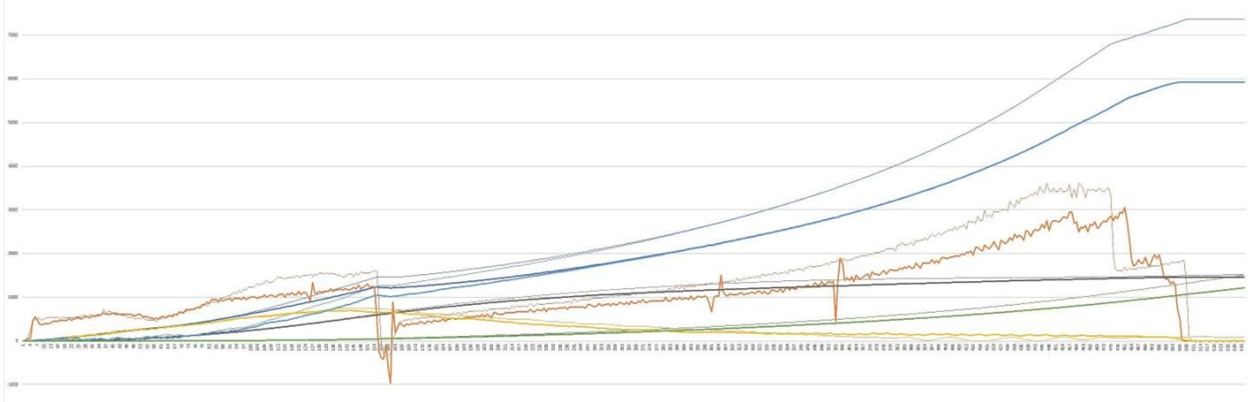

Fig. 6 – IFT-6 and IFT-7 flights (second stages), accelerations – thin and thick purple lines at IFT-6 and IFT-7 respectively, with sharp steps [17]

"Roughly two minutes later [more like 65 seconds, or 6:03 – 6:04, see Fig. 6], another flash was observed followed by sustained fires in the attic. These eventually caused all but one of Starship's engines to execute controlled shut down sequences and ultimately led to a loss of communication with the ship. Telemetry from the vehicle was last received just over eight minutes and 20 seconds into flight.

Post-flight analysis indicates that the safety system did trigger autonomously… and… the vehicle was observed to break apart approximately three minutes after loss of contact during descent. The most probable root cause for the loss of ship was identified as a harmonic response several times stronger in flight than had been seen during testing, which led to increased stress on hardware in the propulsion system".

In order to correctly translate the last two paragraphs of the report quoted above from the specific corporate language into English, let us again refer to Figs. 2 and 3, as well as to description of the second-stage engine failures. At 7:40 (460 s after start and 95 s after the second flare), the central engine performed first "controlled shut down", at 8:02 this happened with the second central engine, and at 8:04 – with the neighbouring outer engine. At 8:18, Ship lost the second outer engine, at 8:23 the last of the three central engines failed, and at 8:26, at an altitude of 146 km, contact with the vehicle was lost [18] – 27 seconds before the planned engine shutdown [19]. It remains unknown when the last outer engine stopped working. Thus, the engine shutdowns lasted no less than 46 seconds.

At the same time, from the data presented in Fig. 3, it can be concluded that the fluctuations in acceleration, and therefore thrust, began quite a long time before the first engine was turned off. The amount of methane in the tank from the time of approximately 8:04 began to decrease significantly faster than oxygen, so that only 16 seconds later, by 8:20 – the last time mark when the background in the frame allowed us to more or less accurately track the readings of the fuel indicators, the residual proportion of methane in the fuel tank was no more than 60 % of what was in the oxidizer tank, see Fig. 7. And the moment of 8:04 is very close to the moment of failure of the first external engine with a vacuum nozzle, if they don't coincide at all, although the fires in the tail section (in the attic) had been going on for a little more than three minutes by this time.

Fig. 7 – Ratio of oxygen and methane in the tanks of Ship during IFT-7 before the loss of telemetry

From all this it follows that, perhaps, the only version that links the described events into a single cause-and-effect chain can only be intense resonant fluctuations of the new methane feeding lines of the external engines (called "harmonic response" in the report), accompanied by fuel leaks, and then destruction of one of them at 8:04, after which methane apparently began to pour into the oxygen tank. Since longitudinal Pogo vibrations are excluded by calculations for this version of methane feeding lines of the engines, the cause of what happened is transverse fluctuations of thin, unsupported methane pipelines. At first glance at the structure shown on the right in Fig. 4, it seems that any engineer should have a thought about possible problems with the transverse stability of these lines when they are placed in an object in which there are external vibrations of a wide spectrum, as in any rocket stage. Moreover, thousands, and even tens of thousands of people could observe the excitation of various modes of transverse fluctuations of the cords on which they suspended submersible vibration pumps, as the level of liquid they pumped changed – when cord came out of the liquid, the damping of its vibrations decreased. So here, with the tank filled with oxygen, as at the beginning of the acceleration or during the ground test, the damping was high, and the methane pipelines, although they oscillated, didn't break down. And when there was little oxygen in the tank, then the upper pipeline, the least immersed in the remaining oxygen, broke off at the attachment point of one of its ends.

If we take into account that the outer engines are rigidly fixed, and the central ones are mounted on gimbals, then the ship's vibrations, especially transverse ones, should have rocked them first, which led to the control system turning them off first even before the destruction of the first methane pipeline, after which the count began in seconds.

The need to fixe long and thin pipelines is a well-known requirement for designers. Apparently, it was for violating it that some SpaceX employees were reportedly fired immediately after the seventh flight [20]. Obviously, methods for securing the methane pipelines were urgently developed, for example, using stretching cords between them and side walls of the oxygen tank, that were tested during the unprecedentedly long ground tests of S34 Ship on February 11, 2025 [21]. After that, the company began intensively preparing for the next Starship flight.

V. Causes of Starship accident in the eighth flight

So, by mid-February, the problem, which arose either due to nonchalance or insufficient competence of previous creators of new version fuel system, was solved, and on March 6, 2025, the eighth Starship launch was carried out [6, 9, 22]. This flight was supposed to follow a program similar to the previous one, only the payload in the form of four mock-ups of Starlink satellites was 2.5 times smaller than in January. Judging by various responses, it was confidently expected that this flight would be completely successful. However, at about the same flight time as in January, an engine explosion occurred, and Ship was lost again. Until now, three and a half weeks later, SpaceX hasn't reported the reasons for the incident, and hasn't made any substantive statements at all. At the same time, media maintains the opinion that the same thing happened in the eighth flight as in the seventh, and that the medicine urgently prescribed to Starship in the short inter-flight period turned out to be worse than the disease.

However, this isn't the case. Analysis of the second, seventh and eighth flights allows us to state that the situation is actually even worse – this work was done properly, but the causes of the last two accidents turned out to be completely different. And what to do with all this now – the company doesn't know.

To prove these assertions, let us compare the information we know about the last two flights. In the previous section of the paper, it was shown that in the seventh flight, the emergency situation developed slowly over a period of no less than three minutes, and the fluctuations of hull structure initially led to the shutdown of central engines, which were mounted on movable suspensions and therefore more susceptible to external influences. And the engine shutdowns occurred over a period of no less than ¾ of a minute, see, for example, Fig. 3.

In the eighth flight, despite the fact that the precursors of the impending accident also existed, the first of them could be noticed only about 20 seconds before the accident – at 7:45, a weak reflection of a short flash of flame appeared in the attic somewhere in the vicinity of the rear cover of the oxygen tank [23], see Fig. 8. Thus, the time of the emergency process development at IFT-8 was an order of magnitude shorter than at IFT-7, and corresponds well to the typical times of development of auto-oscillations of Pogo type.

Fig. 8 – Reflection on the edge of the ship's attic a short flash of flame in its upper part during IFT-8

Now let us return to the consideration of the trajectory data. Fig. 3 shows quite well the process of successive shutdown of Ship S33 engines by the control system in the seventh flight. The chronology of this process is given in the previous section of this work. At the same time, in the eighth flight, at 8:04, the outer engine (with the vacuum nozzle) exploded and stopped working, and, judging by the iconography, in 2 – 3 seconds, and most likely even faster, all three central engines stopped working. The two remaining outer engines, located further from the explosion and protected from it by the central engines, nevertheless continued their work, forcing the ship to perform impressive somersaults, reminiscent of Starship first flight. The answer to the question of why they didn't explode will be given below in this text.

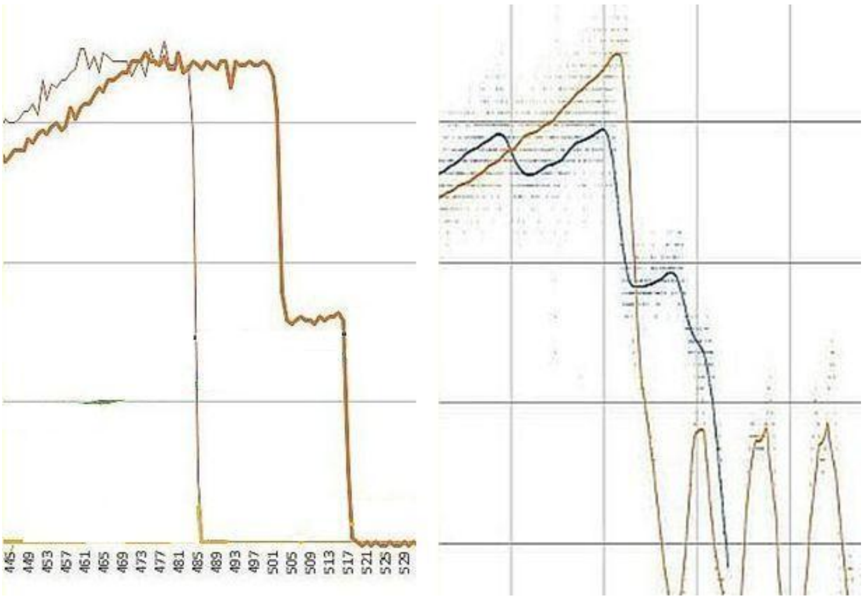

Fig. 9 – Accelerations of Ships at IFT-2, IFT-3, IFT-7 and IFT-8 shortly before the engines stopped working

It should be noted that, with the exception of this moment, the development of the second stage failure at IFT-8 is very similar to what happened 15.5 months ago at IFT-2, see Fig. 9, the left part of which shows the accelerations of Ships before the failure at IFT-2 and before the completion of the boost at IFT-3, and the right part shows similar accelerations at IFT-7 and IFT-8 before new failures. The graphs are reduced to the same scale, different smoothing criteria lead to different smoothness of the compared curves. The similarity of the failures in the second and eighth flights is undoubtedly, as is their difference from the failure in the seventh flight.

We will also demonstrate the proportions of fuel components residuals in Ships' tanks during IFT-2, IFT-7 and IFT-8 at the culmination moments of their accidents [9, 18, 24], see Fig. 10.

Fig. 10 – Oxygen and methane ratios in the tanks of Ships at IFT-2, IFT-7 and IFT-8 at the culmination moments of the three accidents

During the normal course of the process, the proportions of the remaining fuel in the rocket stage tanks should be approximately the same, which is usually the case. When watching the videos of all eight flights of Starship, you can sometimes see some deviations from the equality of the proportions of methane and oxygen, especially at the moments of accidents. Even in Fig. 10, you can see that in the second flight, at the moment of engine shutdown, the proportion of oxygen was slightly less than the proportion of methane (see the upper window of Fig. 10), and in the eighth flight, it became slightly larger than the proportion of methane (see the lower window). This could be due to the inaccuracy of the fuel level sensors, as well as leaks of its components – without this, the fires in the attic, apparently, wouldn't have been possible. However, all these leaks are so small that they are quite difficult to see on the corresponding indicators. But in the seventh flight (see the middle window) the difference in the shares of the components, which arose in just ~ 15 seconds, is very large, despite the fact that by the beginning of this phenomenon, half of the engines had already turned off, and the fuel consumption had decreased at least twice compared to the nominal. It is worth noting that in the eighth flight at 8:20 the sensors showed more liquid in the oxygen tank than in the seventh flight 15 seconds before. It is quite obvious that with transverse vibrations of long and thin pipelines, their destruction begins at the place where their ends are fixed, therefore, it can be expected that methane from a damaged or even destroyed pipeline began to get into the oxygen tank, as a result of which an unprecedented disproportion in the fuel components arose at that moment.

There was nothing like this in either the second or the eighth flights. Initially, the author, who didn't have a scheme of the methane pipelines in the second stage at that time, assumed that the length of the oscillatory circuit from the methane tank to the engine pump also included the height of the oxygen tank. In this case, no auto-oscillations of Pogo type with oscillations in the methane feeding lines could be excited. And Pogo process with oscillations in the oxygen circuit was possible in principle. Therefore, the explosion of the second stage in the second flight was explained by this process [11].

However, shortly before the seventh flight, the scheme of Ship fuel system, both the first and second versions, were posted. And it turned out that with the real configuration of methane supply lines, Pogo could well have occurred (see Section III of this work). And the change in the architecture of these lines in the second version of Ship, directly and unambiguously showed that Pogo process with oscillations of methane was in the second flight. At the same time, the real parameters of the oxygen pipelines didn't contribute to the occurrence of such auto-oscillations along this channel in the first version of the vehicle.

In the new version, Pogo option with methane oscillations was excluded. However, the elongation of Ship, an increase of almost 20 % of its mass, as well as a probable change in the length of the oxygen feeding lines due to the flattening of the lower shell of the oxygen tank, led to some change (probably an increase) in the frequency of hydroacoustic oscillations in the engine oxygen supply system, and to an even more significant decrease in the frequency of own elastic oscillations of the hull. And this, as follows from the results of the eighth flight, still led to the emergence of Pogo option with oscillations in the oxygen flow. That is, the assessment of the causes of Ship explosion in the second flight, which wasn't justified due to the lack of necessary data, more than a year later, after the design changes were made to the vehicle, returned to the developers of Starship system, like a boomerang thrown then. This seems to be a manifestation of some kind of higher justice for their actions a year ago. Maybe it wasn't in vain that it was once written: "Vengeance is mine, I will repay".

Without a full-fledged theory, they, having pulled out their tail, got stuck nose-deep in the same swamp. And what's more, the mechanism for combating Pogo, based on formula for recalculating the frequency of hydroacoustic oscillations according to the operating mode of Raptor-2 engines, which they demonstrated with some brilliance, as well as noise and explosions in the first half of 2024, stopped working due to the current circumstances. And, one must assume, SpaceX doesn't know what to do with Pogo now. Other, more complex mechanisms for combating Pogo will require significantly more effort and time, but, by the way, they have already lost more than a year. In addition, without a theory, they don't know in advance when they will have to face Pogo again, and will be forced to repeatedly continue their path from accident to accident, the first time they passed last year.

And finally, let us try to answer why two outer engines continued to operate after the accident. They were apparently not seriously damaged by the explosion of the first engine due to Pogo. The development of this process was also underway in them, but due to small differences in the operating conditions before the accident, it didn't have time to move on to its final phase. The differences in operating conditions could have been due to the fact that in the flight position of the ship, the liquid oxygen level was significantly deviated from the plane normal to its longitudinal axis, and the hydrostatic pressure values, which also contributed to the pressure levels at the inlet of the engine pumps, were different. And the higher the pressures at the inlet of the pump, the lower the pressure drop on it, and the higher the frequency of hydroacoustic oscillations. The difference was small, but it was enough for one engine to explode, and the other two didn't have time to do so. After the accident, the system's characteristics changed dramatically due to the release of liquid oxygen and boost gas, as well as the appearance of noticeable and rapidly changing inertial loads due to pirouettes of Ship S34, and under such conditions Pogo could no longer disrupt operation of the engines.

It should be noted that in the seventh flight, first of the external engines had to fail was the one with the smallest part of methane supply pipeline immersed in liquid oxygen, and in the eighth, on the contrary, it was the engine with the thickest layer of liquid oxygen above the liquid oxygen intake opening. Consequently, these had to be different engines. And, indeed, if the iconography of the seventh and eighth flights identically displayed the location of Ship's engines relative to its horizontal plane, then, in accordance with this data, this is how it was – in the seventh flight, the left (according to Fig. 10) external engine (see video [18]) was the first to stop working, and in the eighth, the right one exploded.

Conclusions

1. The failures of Starship second stage – Ship Block 2 in the last two flights occurred for two different reasons. In the seventh flight – due to the occurrence of transverse fluctuations of new design pipelines for feeding methane to the external engines with vacuum nozzles, and in the eighth – due to the occurrence of longitudinal auto-oscillations of Pogo type with hydroacoustic oscillations in the oxygen feeding lines.
2. The new design of methane pipelines to external engines arose from the need to prevent longitudinal auto-oscillations of Pogo type with hydroacoustic oscillations in these pipes.
3. Thus, at the very first attempt to change the design of Starship system so that it would be able to launch at least a minimum payload into low Earth orbit, SpaceX Company completely devalued all their achievements obtained during the overcoming of the first crisis of the Starship program associated with the various Pogo variants that plagued this rocket system.
4. This casus arose because the previous methods of suppressing Pogo at the new phase of the program became practically inapplicable, and also because it was impossible to predict before flight where, when and why the auto-oscillating process would arise and whether it would arise at all this time. It is too expensive start a series of test flights anew every time the design of Starship system is changed to work it out.
5. This is the main content of the second, and apparently so far the deepest crisis of the Starship program. Tot having a full-fledged theory of Pogo due to the desire of the company's management to hide the very fact of the special susceptibility of this rocket system to various types of longitudinal auto-oscillations, SpaceX Company will be forced to blindly fight the manifestations of Pogo, which here and there unexpectedly appear on new versions of the system, like an underground fire in a dried-up peat bog.

Links

1. Yu. I. Lobanovsky – Secrets of Starship test program: Analysis of its first phase main problems. *Synerjetics Group*, 08.03.2025, 10 p. // http://www.synerjetics.ru/article/starship_problems_eng.htm
2. SpaceX Starship. *Wikipedia* // https://en.wikipedia.org/wiki/SpaceX_Starship
3. J. Roulette – SpaceX's Starship to deploy mock satellites in next test. *Reuters*, January 3, 2025 // https://www.reuters.com/technology/space/spacexs-starship-deploy-mock-satellites-next-test-2025-01-03/
4. Yu. I. Lobanovsky – Two episodes from the history of astronautics: Similarities and differences. *Synerjetics Group*, 06.05.2024, 10 p. // http://www.synerjetics.ru/article/two_episodes_eng.htm
5. Starship's Sixth Flight Test. *SpaceX*, November 19, 2024 // https://www.spacex.com/launches/mission/?missionId=starship-flight-6
6. Starship's Eighth Flight Test. *SpaceX*, March 6, 2025 // https://www.spacex.com/launches/mission/?missionId=starship-flight-8

7. First-hand: details of Starship S34 crash. *Техасский Вестник.* 09.03.2025 // https://t.me/starbasepost/2242 (in Russian)
8. Dedarkener – Starship IFT8 Acceleration Profile. *R/spacex*, March 8, 2025 // https://www.reddit.com/r/spacex/comments/1j6kj57/comment/mgpbtny/?context=3&rdt=62211 (in Russian)
9. Video. *SpaceX*, March 6, 2025 // https://www.spacex.com/launches/mission/?missionId=starship-flight-8
10. Yu. I. Lobanovsky – Causes of Starship both stages crashes on second flight. *Synerjetics Group*, 04.12. 2023, 10 p. // https://www.synerjetics.ru/article/second_flight_eng.htm
11. Yu. I. Lobanovsky – Mechanism of Starship first stage explosion during its return maneuver. *Synerjetics Group*, 12.01.2024, 7 p. // https://www.synerjetics.ru/article/boostback_eng.htm
12. Bigger is Better: Starship's Extended & Optimized Tanks. *Ringwatchers*, December 24, 2024 // https://ringwatchers.com/article/s33-tanks
13. Yu. I. Lobanovsky – Hydroacoustic theory and problems of Nurek HPP. *Hydropower of Ukraine*, no. 4, 2014, 18 p. // http://www.synerjetics.ru/article/nurek.htm (in Russian)
14. N. N. Arshenevsky, M. F. Gubin, V. Ya Karelin et al. – Hydroelectric power stations. Moscow, Energoatomizdat, 1987, 82 p. // https://leg.co.ua/arhiv/generaciya/gidroelektricheskie-stancii.html (in Russian)
15. SpaceX. *X*, January 3, 2025 // https://x.com/SpaceX/status/1875219215390757043
16. New Year. New Ship. New lessons. *SpaceX*, February 24, 2025 // https://www.spacex.com/updates/#flight-7-report
17. OneSpeed – Re: Starship Flight 7 UPDATES : Starbase TX : 16 Jan 2025 (22:37 UTC). *NASASPACEFLIGHT*, Reply #198, January 17, 2025 // https://forum.nasaspaceflight.com/index.php?topic=61946.msg2657209#msg2657209
18. Video. *SpaceX*, January 16, 2025 // https://www.spacex.com/launches/mission/?missionId=starship-flight-7
19. Starship flight test 7. *Wikipedia* // https://en.wikipedia.org/wiki/Starship_flight_test_7
20. Space Sudoer – From what I'm hearing… *X*, February 2, 2025 // https://x.com/spacesudoer/status/1885707775017398321
21. Starship long-duration static fire ahead of the eighth flight test #IFT8. *YouTube*, February 11, 2025 // https://www.youtube.com/watch?v=NRmvhof08sE
22. Starship flight test 8. *Wikipedia* // https://en.wikipedia.org/wiki/Starship_flight_test_8
23. Replay! SpaceX Starship launches on flight 8, catches booster but loses ship again. *YouTube* // https://www.youtube.com/watch?v=32Z1ZUxxObs
24. Video. *SpaceX*, November 19, 2024 // https://www.spacex.com/launches/mission/?missionId=starship-flight-6

I would like to express my gratitude to V. I. Konkov for useful discussions of the issues considered in this work.

Moscow,
30.03.2025

Yu. I. Lobanovsky