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Chapter 15

The Rocket Flight Stability Problem: A History of Misconceptions*

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At the dawn of rocketry priority lay in the creation of a serviceable rocket engine. Before long, however it appeared that rockets with a well-running engine were incapable of performing even the simplest trajectory—a vertical climb. Thereafter, the problem of ensuring a stable flight along the prescribed trajectory was realized as no less important than the creation of a reliably running rocket engine. As a result theoretical works emerged, dedicated to this actual problem: rocket structure, following theoretically developed principles. Unfortunately, most of those works graphically revealed the author's inability to comprehend the core of the problem. Hence rocket structures, based on discovered principles, appeared ineffective.

Initially, the task seemed to have quite an easy solution, because after all, there had been rocket artillery in the past and today fireworks rockets shoot high up in the air. This reasoning didn't take into account that the operating conditions, as well as requirements both for fireworks rockets and for rocket projectiles, differed widely from those for liquid-propellant rockets.

During the first stage, a stable and prolonged vertical flight was required of liquid propellant rockets. Both the active and passive flight legs were equally important, because with the help of such launchings it was ultimately expected to be able to achieve a height unattainable by airplanes and even stratospheric balloons. The task seemed to have a simple solution: it was necessary to pro-

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vide a vertical climb with a live engine, with the rocket continuing the climb "on its own" during the inactive flight leg. Such a supposedly simple solution was based on daily practices; when a sled is pulled it keeps on a moving, but when, instead, it is pushed forward it immediately tries to divert course. Thus it was concluded that the flight stability could be easily achieved by putting the engine in the forebody of the rocket, and not in its afterbody, where the engine would start "pushing."

Robert H. Goddard followed the same erroneous idea for his first rocket (1926). The rocket engine was fixed far ahead of the propellant tanks. This was Goddard's only rocket of that type. All the rest of his rockets were built in accordance with the currently accepted scheme—with the engine in the rocket's afterbody. He saw at once that since the engine rotated together with the rocket, the engine thrust would always be directed towards the rocket's center of mass, if such was the initial adjustment. Thus, in rocket rotation no engine torques could appear, wherever the engine was fixed.

The above simple reasoning turned out to be beyond the German enthusiasts of the early 1930s. Johannes Winkler's rocket (1931), the subsequent Mirak 1 and Mirak 2, as well as a vast number of others were characterized by the engine position in the rocket nose cone. The rocket launched at the Army Proving Ground at Kummersdorf (1932) had the same configuration (Figure 1).

All this looked like an epidemic. Even Rudolf Nebel's famous rocket that was to take a man into the air in Magdeburg (which, fortunately, didn't even start), had a "pulling" engine.

This general enthusiasm for the seemingly simple, but basically erroneous, way of obtaining a stable flight found even a "theoretical justification." Guenter Press's article (1936)[1] gave a completely incorrect explanation of the stabilizing effect, allegedly resulting from the front position of the rocket engine. A year later, O. Steinitz in his article (1937)[2] convincingly criticized Guenter Press's error. Nevertheless in 1941, in his work on rocket flight stability, G. Janson again claims, that "stable flight is ensured, when the moving force's center is located in front of the resisting forces center" (here the motion resistance forces are understood as aerodynamic forces and weight). Both German rocket structures of the early 1930s, and the corresponding theoretical articles show a total failure of rocketry enthusiasts to understand the simplest problems of flight mechanics.

To the credit of Soviet rocket engineering, all rockets authored by them (1933) had a normal design. Somewhat unexpected might appear to be the structure of Hermann Oberth's Mediash rocket (1935). It also had a nose cone fixed engine, but his books (1923 and 1929) clearly prove his understanding of the fact that such an engine position does not produce any stabilizing effect.

The essential reasoning behind this was obviously different. The rocket was built to achieve high altitudes, which, in turn, is connected with a long inertial lifting leg after engine stoppage. To ensure a maximum climbing altitude during that inactive leg of the trajectory, the aerodynamic drag of the rocket with a dead engine had to be reduced to a minimum. If the engine is in the rocket afterbody its "cut-off tip" would give increased resistance after the engine is cut off.

Oberth fixed the engine in the rocket nose cone, and thus made its body aerodynamically perfectly shaped (Figure 2). Besides, he expected to achieve a certain stabilizing effect. Rocket attitude stabilization was attained with the help of fitting sufficiently strong tail fins (like those of an ordinary arrow), which created stabilizing mechanical movements, under the airflow. The tail fins were effective enough at high-speed rocket flight, but at the very beginning of the start, with the rocket velocity still low, the emerging aerodynamic forces could be insufficient.

They could be increased by placing the tail fins into the rocket engine's gaseous jet, which was what Oberth might have meant. He was absolutely free from erroneous considerations concerning the importance of fixing the moving force's center ahead of the "resisting force's" center.

The above-mentioned seemingly reasonable considerations justify the forebody rocket engine position, but this is actually not so. The defects of such a position undoubtedly outweigh all possible advantages. Among the major defects are the following two: (1) engine hot gases, flowing around the rocket body, created additional design difficulties and, besides, increased the aerodynamic drag of the rocket; and (2) the engine's gaseous jet efflux must be relatively symmetrical (to the rocket axis), otherwise there occurs a moment when its body turns, and this destabilizes it.

Such a symmetry could to a certain extent be attained, if the jet axis of the engine coincides with the axis of the rocket itself, but it is practically unattainable, when instead of one jet on the engine there are two or more, which are perceptibly distanced from the axis of the rocket, as it is impossible to get an absolutely equal combustion and gas efflux from different nozzles. By the way, though the above mentioned German enthusiasts' rockets of the early 1930s had a front position engine, they always had only one nozzle, directed along the axis of the rocket, which is why their creators did not confront the above difficulty. Naturally, Oberth understood that the radical solution of the flight stability problems was the application of gyroscopic instruments for automatic control (as his letters show), but he could not get around to the implementation of the idea at Mediash.

An attempt to understand the problem of rocket flight stabilization during vertical lift-off led to a transition from general reasoning to a mathematical treatment of the question. Two articles by M. Tikhonravov published in 1935[4] and 1938[5] have to be mentioned here. The common ground in these articles as well as in those mentioned above (boiling down to general considerations) was that they always examined attitude stabilization and, in connection with it, mechanical movements influencing the rocket.

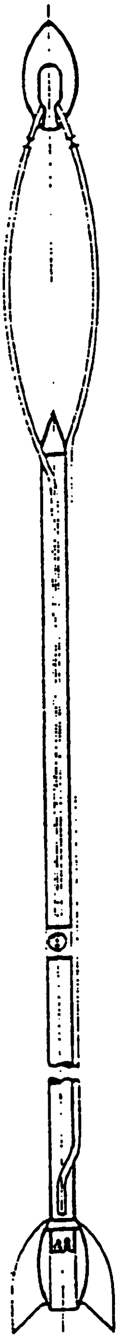

Figure 1

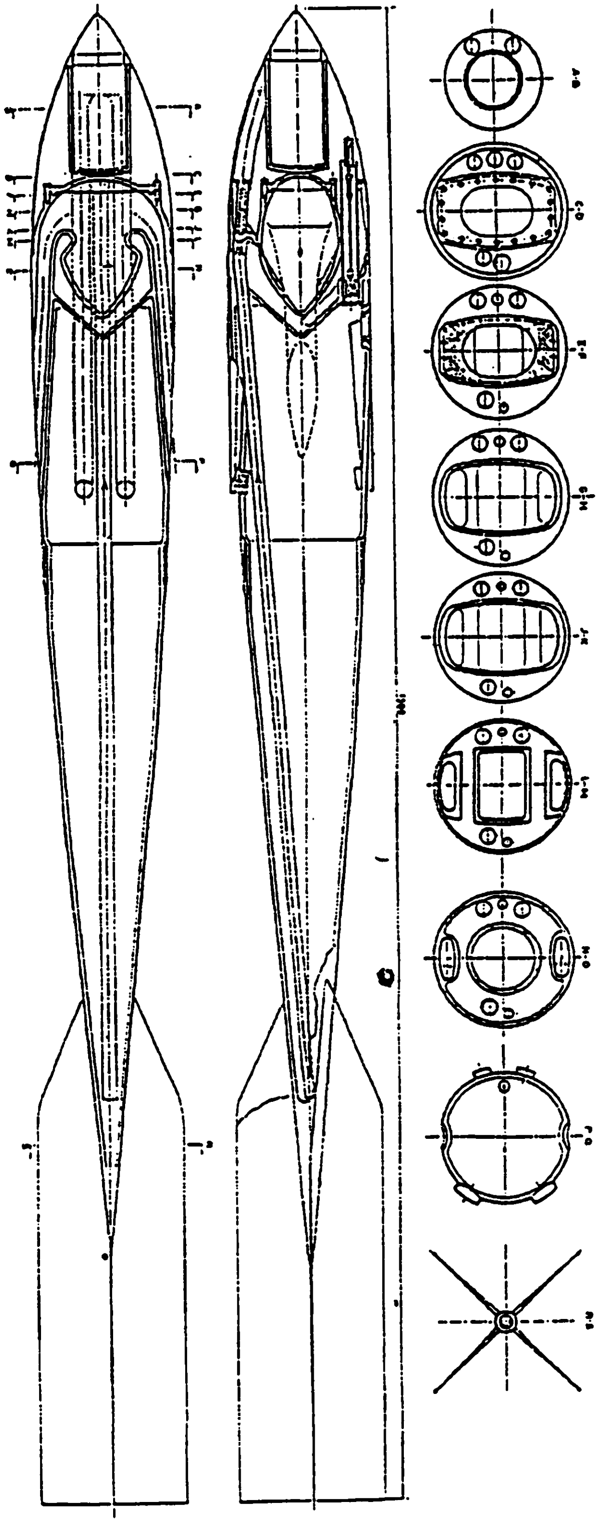

Figure 2

This testifies to the above-mentioned complete misunderstanding by the authors of the causes of a vertically climbing rocket's unstable flight. It was quite easy—and those articles looked at it—to obtain the required attitude stabilization (so that the axis of the rocket always corresponded with the direction of the velocity), but it is a serious error to think that thereby the stabilized flight (vertical trajectory) would be attained.

Without going into detail, it is sufficient to state that the ascending rocket's trajectory deflection from the vertical results from the interaction of forces, and not from mechanical movements, and the character of this interaction is such, that a stable vertical climbing is impossible in principle, whatever design tricks are resorted to (thus no theories regarding mechanical movements, influencing the rocket, can explain its unstable flight). The only way out is the use of control devices (i.e., gyroscopic instruments).

The first rocket with gyroscopic stabilization was Alfred Maul's solid-propellant rocket, intended to photograph enemy positions (successfully tested in 1906). It used the direct stabilization principle (and not the control-surfaces deflection one), and for that purpose had a fairly massive gyroscope, which started spinning before ignition.

Conceptually identical was the vertical climb stabilization of the two A-2 rockets, constructed by Wernher von Braun and tested in 1934. Their direct stabilization gyroscopes were rather massive—the gyroscopic mass was 40 kg. Although those rocket flights were wholly successful, it was clear that the direct stabilization principle used in them did not essentially resolve the problem, because already Oberth (1929) had shown that rockets would boost with curvilinear trajectories, while the method used in the A-2 rocket was only suited to straight line flight (i.e., vertical climb). No wonder the following von Braun A-3 rocket (tested in 1937) was already controlled by a gyroscopic instrument responding to on control-surfaces deflection.

The first rocket of the type to take off was Goddard's, tested in 1935. It had a gyroscopic stabilizer turning tail rudders if a vertical deflection of the rocket exceeded 10°.[7] As it is evident from the overview, the autostabilizer was also only intended for vertical climbing. Unlike the A-2 rocket, Goddard's control diagram with a gyro-controller, signaling only the rocket attitude excursion and with the respective effect on the body implemented by some or other tail rudders, opened up a fundamental possibility of rocket flight stabilization along a prescribed curvilinear trajectory. Therein lies the epoch-making significance of Goddard's rocket. However, the control diagram in it was still imperfect. First, only two vertical deflection angles were stabilized, and rocket rotation about its axis was permitted (that was impermissible when setting curvilinear trajectories). Besides, there was a too late and sharp deflection of tail rudders which caused the rocket to enter a self-oscillation regime, and not that of a stabilized flight, with angular deflections of up to 30°. Nevertheless, it was the first flight with an autostabilizer.

A similar rocket was developed in the USSR in 1935-1936. It was meant to follow the GIRD-09 and the GIRD-X rockets and was equipped with a gyroscopic stabilizer similar to Goddard's (index—GPS 2). But unlike Goddard's gyro-stabilizer it was characterized by a more perfect linear (smooth) response to rocket deviation, and could hold the vertical flight direction more accurately than Goddard's. Both the rocket and the autostabilizer (a gyroscopic autopilot) were manufactured but the rocket was not tested, as the institute, where it was designed and manufactured, turned to armaments.

German enthusiasts, working under Rudolf Nebel's supervision at the Raketenflugplatz or "rocket flying field" in Berlin-Reinickendorf (1930-1934), dared not even dream of automatic flight control devices (although Oberth spoke about their necessity in his books). That speaks of a very low qualification of these enthusiasts. Thus, it was not surprising that von Braun was put in charge of developing liquid-fuel rockets but not Nebel.

The first "real" rocket, with a complete automatic control system for flying along any curved trajectory and with a high path accuracy, was an A-4 rocket, designed under von Braun's supervision. It served as a prototype for all subsequent rockets and it finishes a "history of errors." And then comes a "history of improvements." This rocket responded not only to rocket attitude excursions, but also to its center of masses deviation from the prescribed trajectory (here we won't describe this control device realization). It was an outstanding achievement that paved the way for the further development of space rocketry.

Summary

In the 1930s enthusiasts of rocketry, especially in Germany, while launching their small liquid-propellant rockets, expected to achieve stable flight through simple design measures. They overlooked the fact that a rocket missile was conceptually an unstable flight vehicle. Only the A-4 rocket worked out by von Braun with a perfect control system paved the way for space rocketry.

Reference Notes

[1] Press, Guenter, Zur Stabilitaet der Rakete, *Das neue Fahrzeug*, No. 3, 1936.

[2] Steinitz, O., Zur Stabilitaet von Weltraum-Raketen, *Das neue Fahrzeug*, No. 1/2,1937.

[3] Janzon, G., Die Eigenstabilitaet der Rakete, *Weltraum*, Heft 1, 1941.

[4] Tikhonravov, M. K., Ustojchivost' poleta rakety, Sb. "Reaktivnoe dvizhenie," ONTI, Moskva-Leningrad, 1935.

[5] Tikhonravov, M. K., Ustojchivost'vertikal'nogo poleta rakety. Sb. "Reaktivnoe dvizhenie," No. 3, Moskva-Leningrad, Oborongiz, 1938.

[6] The real specimen of Maul's rocket and his gyroscopic stabilizer can be seen at the "Deutsches Museum" in Munich.

[7] Goddard, Robert, Liquid-Propellant Rocket Development, Smithsonian Institution, Washington DC, 1936. (Publication 3381).