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Chapter 14

The Earliest Romanian Publication on Astronautics in 1929[*]

Radu D. Rugescu[†]

Introduction

Far before the dawn of spaceflight, the earliest Romanian scientific publication in astronautics entitled "Problema astronauticei şi a navigatiei deasupra stratosferei" ("The Problem of Astronautics and Navigation above the Stratosphere") is published in the Bulletin of the Polytechnic Society in Bucharest, Romania, from December 1929[8] by the famous Romanian scientist Acad. Professor Emeritus Dr. Doc. Eng. Dorin Pavel as the written form of his public conference broadcasted at radio station "Romania" the same year. It came at a time when a strong dispute was already engaged around astronautics, felt rather as fantasy or madness than a science, and the author had the capacity to vigorously demonstrate, in a rigorous manner, the feasibility of rocket propulsion for spaceflight. To eagerly support the newly published book of Hermann Oberth in 1929,[3] Pavel rebuilt the mechanical equations for a rocket flight in vertical and horizontal direction, under gravity and emphasizing possibly the earliest concept and definition of the mechanical efficiency of the rocket motion, a known subject of dispute even today. He found that good efficiency is only attained at high speeds and any prospects to use rocket propulsion for slow vehicles, like cars or boats, would not make sense.

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He approached in this regard the supersonic aerodynamics, referring to the incipient, for those 1920 years, experimental research at Göttingen in Germany. The paper ends with a strong call for thrust and investments in astronautics, its author proving to be a supporter and forerunner of astronautics in Romania.

Romania and Astronautics by 1929

The visitor who steps along the entrance of the Smithsonian Institution National Air and Space Museum in Washington D.C. faces four huge photographs. The portraits belong to Konstantin E. Tsiolkovsky, Robert H. Goddard, Hermann Oberth, and Wernher von Braun. These four founders of astronautics were actually accompanied by a number of actively involved supporters and a growing mass of specialists. Due to a lot of unknown factors for that time regarding high velocity flights and the accessibility of lightweight but powerful rocket engines for actual applications, the publications of the time lacked the scientific level necessary to support the new and apparently irrational idea of spaceflight. The disorientation of a great specialist like Ludwig Prandtl, while reviewing and rejecting the Ph.D. thesis of Hermann Oberth, or that of Prof. Franke,[19] with his famous remark "*something is wrong, still I can't find where the mistake is*" looks typical. This explains why, although the bolster toward space was steadily emerging, it was more the realm of Science-Fiction, beyond Jules Verne. Victor Anestin (1875-1918) did publish in Romania in 1899 the longer targeted fantasy *Calatorie la Venus* (*Voyage to Venus*). Returning to the Moon flight, in 1907 the first Romanian imaginary lunar flight *O calatorie in Luna* (*A travel in the Moon*) was published by Alexandru Sperantza.[21] Other works bear particularly courageous ideas, as for example the anti-gravitational propulsion system, imagined in 1914 in Bucharest by Henric Stahl (1877-1942) and published with the title *Un român în lună* (*A Romanian on the Moon*), based on a fictitious material called Cavorite. The title of the 1930 Fritz Lang's movie *Frau im Mond* (*A Woman in the Moon*)[19] is similarly concise to the Stahl's novel.

Up to 1929 the idea of using rocket propulsion for high speed, high altitude flights remained very crude and almost unknown to the people. The first and little disseminated American monograph of Robert Goddard[1] was only ten years old, while the famous book of Hermann Oberth from 1923[2] was almost of the same age. The pioneering contributions of Tsiolkovsky from 1903 and of his predecessor Feodorov, were in fact unknown at all. However, a sensible quantity of actions in support of a vivid science of astronautics was already produced. There were societies in many countries, there were international conferences, and by 1929 there was the second book of Oberth,[3] the books of mere science by Max

Valier[4] and A. B. Scherschevsky[5], while the influential book by Walter Hohmann[6] stayed at the threshold between astronautics and celestial mechanics.

Beyond Oberth, few high level scientific papers ware published. Apparently the first mathematical paper on the variational solution for optimal, vertical atmospheric ascent of the rocket vehicle appeared in ZAMM in December 1927.[16] This math work was unfortunately accompanied by no detailed numerical results (see below). We learned eventually that by 1926 the first, incipient rocket tests by Robert Goddard were performed in America and prior to 1929 a lot of primitive experiments with rocket engines were occasionally performed elsewhere.

We also learned that the earliest patent of and experiments with a reversed hybrid rocket engine were recorded in 1886 in France.[7]

The first Romanian paper here described[8] is adding to the few, early theoretical pleadings for space technology worldwide. Consequently, the rising science of astronautics remained to be yet perceived for long as an esoteric, unpractical target, largely intellectual, although fascinating. A year only after the paper here described was issued, the famous fantasy movie *Frau im Mond*, makes news and introduces forever the presently familiar "count-down" of future space launches.

Worth recollecting is that Jules Verne actually announced astronautics almost a half century before. Visionary practitioners were still waited however, in order to actually boost this progress. The explosive, industrial scale development of rocketry will only appear in Germany right before World War II. We are still in 1929 only, and Romania has just evolved after the end of World War I into a large and fast advancing country. A rapidly evolving industry in general and aeronautical industry in particular were structured in Romania of that time. Aeronautics was actually a national dedication, on the grounds of Romanian resonant pioneering achievements in aeronautics and astronautics by Traian Vuia 1906, Aurel Vlaicu 1910, Henri Coandă 1910, and Hermann Oberth 1923. The first airplane factories in Bucharest were ICAR (Romanian Enterprise for Aeronautical Constructions) and ASAM (Administration of Stabilities for Aeronautics and Marine). After the first forerunners mentioned above, Dr. Elie Carafoli marked since 1926 the aeronautical history with his widely known books in aerodynamics. Carafoli would eventually become the president of IAF (International Astronautical Federation). While aeronautics was in constant progress, astronautics was a mere work of Science-Fiction mainly. Along this streamline, there are unconfirmed statements that in Romania, even in 1912, the first crude experiments with solid propellant rockets were performed by Ion Stoescu, a sound designer of early wind tunnels in France and Romania.

In this effervescent environment entered Hermann Oberth, the Romanian physicist of ancient German extraction, born in 1894 in Sibiu (Hermannstadt) in Transilvania, who was later professor in physics at the high school in Cluj.[19]

A new and enlarged edition of his first book was issued by Oberth as *Wege zur Raumschiffahrt* (*Ways to Spaceflight*) in 1929.[3] The new book, largely unusual in its concept, generated instantly an utter dispute.[19] The impulse of Dorin Pavel to support the advanced vision of Oberth was irresistible and thus the first Romanian scientific paper in astronautics was written and published by Dorin Pavel in Bucharest,[6] followed soon by a second version.[9] Although a pioneering work, written more than 80 years ago in an incipient space science environment, one recognizes in the article the features of a high-level scientific research, focused on the actual effectiveness of space propulsion.

Dorin Pavel (1900–1979)

In the year 2000 Romanian engineers feverously celebrated the 100th birthday of Professor Dorin Pavel (Figure 14–1), as the "Founder of the national Hydroenergetics" in Romania. A real forerunner in the advancement of both science and engineering, by no surprise he was the first Romanian author in the science of

Figure 14–1a: Dorin Pavel in 1954.

Figure 14–1b: Dorin Pavel in 1929 (Family archives).

astronautics. Born on the 31st of May 1900 in Sebesh (Mühlbach), in his Romanian family of German culture, the same that also gave the most prominent Romanian system philosopher and poet Lucian Blaga,[20] Dorin Pavel manifested a visible and early attraction toward physics and hydraulics.

As a young baccalaureate he went to study fluid mechanics in Switzerland with Aurel Stodola and Franz Prášil, receiving some help from his parents and a great help from his own hard work. He graduated with high distinction from the Polytechnic Institute in Zürich, as "valedictorian" for the year of 1923, so that his name is engraved and can be seen today on the marble front wall of the famous Polytechnikum building in Zürich.

With a Ph.D. degree[10] from the same Polytechnic university of Zurich in 1925 and a position of a very young "senior lecturer," he made the stunning choice to return to Romania, despite the persistent request of his magister Prof. Franz Prášil to remain as Associate Professor to the chair in Switzerland. Romania was however an impressively developing country in those years and attractive for a lot of foreign specialists. Once in Romania, Pavel soon became the founder of the National Hydroelectric System,[11] with the Iron Gates power plant on the Danube for example. He became also a beloved professor in hydraulics along 56 years of tenure at University "Politehnica" of Bucharest. He was a distinct member of the Romanian Academy of Sciences since 1935. As a passionate engineer he entered also in the first line of aeronautic[12] supporters and fighters for astronautics.[8, 9] A bust statue of the Professor honors his memory in front of the Hydraulics Chair at UPB today.

But why a fight in Romania around astronautics that early?

The Article in 1929

During those years the bad, counterproductive custom in Romania was to minimize the merits of national creators in arts and sciences. Oberth had already authored his book *Die Rakete zu den Planetenräumen* (*By Rocket into Planetary Space*) published in Berlin in 1923,[2] disseminated worldwide, that marked the actual beginning of astronautics. And then later, in 1929, Oberth's second book on astronautics came out.

The common people used to ridicule any new and unusual idea developed by a national mind and the unexpectedly advanced ideas of Oberth suffered the same treatment, unfortunately. This unjust treatment has to have a counteraction from a credible scientist, and this mission was assumed by Dorin Pavel.

Besides his expertise in hydraulics, Professor Pavel was also involved in aerodynamics and flight mechanics at the university. He tediously deduced again the main formulae of rocket ascent and found that the proposals of Oberth were all correct. He thus decided to sustain Oberth and the investments in astronautics and his two articles on the matter were published in December 1929. As he proved the principles of rocket flight entirely valid, Pavel, with his practical feeling draw a particular attention to the efficiency of rocket propulsion systems.

It seems ridiculous today that aeronautical scientists were believing that no rocket could perform a flight with greater velocities than its jet exhaust relative velocity. Thus it was the time for Pavel to first prove the rocket equations once again and try to physically explain the mechanical efficiency that actually backs the rocket flight into space.

The Rocket Equation

The conservation law of momentum was seen as the means to evaluate the propulsive effect of the expelled mass of a rocket vehicle and to calculate the thrust acceleration:

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -\frac{C}{M}\frac{\mathrm{d}m}{\mathrm{d}t}. \tag{1}$$

Notice that the static pressure force of the ejected gas is introduced in the effective exhaust velocity C, or the vacuum specific impulse, as in many usual works on the subject. Final speed levels above 3,000 meters per second (m/s) are thus proved by the author, an argument to see in rocket propulsion as the only means to achieve hypervelocity flights.

It is also emphasized in the article the growing flight efficiency with growing altitudes, because the air drag continuously diminishes as air density does, for example, by the law:

$$D = \frac{\rho}{2} C_D S V^2 \tag{2}$$

where he used the power formula $\rho = \rho_0 (1 - 0.02H)^{4.256}$ to approximate atmospheric density. For very high altitudes the formula $\rho = \rho_0 0.896^H$ is suggested. The insight of Pavel into the supersonic drag serves as a metric of the knowledge level in the supersonic aerodynamics in the third decade of the 20th century.

The Air Drag

Pavel considered the quadratic drag in (2) as only valid with constant drag coefficient C_D for incompressible flows. All known data on supersonic air drag was regarded at that time to the artillery shells and all of the following refer to the coast flight only. Pavel makes use of a modifying coefficient k, as introduced by C. Cranz and K. Becker, to cover the compressibility effects, namely[8]:

$$C_D = k C_{D_0} \tag{3}$$

This extra coefficient is described as constant and equal to 1 up to roughly 300 m/s velocity, to jump up to a value of 2.9 at Mach 1 and restoring toward an asymptotic value of 1.5 at advanced hypersonic velocities. In fact the coefficient k is defined as:

$$k = \frac{C_D(M)}{C_{D_0}}$$

and an instructive item is to examine the today's observational values of k versus those presumed in 1929 (Figure 14–2). The dotted line corresponds to the values for "Sandhawk" single-stage rocket vehicles,[13] while the variation due to Cranz[8] from 1929 refers to some artillery missiles. The comparison is done with values revealed by U.S. "Sandia" National Laboratories within the "*Sandhawk*" program,[11] results of a great amount of wind tunnel and in-flight RADAR tracking data, accurately processed. We find that not only the supersonic, as also the incompressible drag values considerably differ,

$C_{D_0} = 0.09$ (Pavel[8])

$C_{D_0} = 0.63$ (Actual[13])

and prove being seven times underestimated in the old works[8, 9] cited by Pavel.

Combining these figures with the compressibility effect in Figure 14–2, the absolute values of the drag coefficient versus Mach number (Figure 14–3) results. It is also seen that the steep variation of the drag coefficient at the sonic line was not yet perceived in the 1930s.

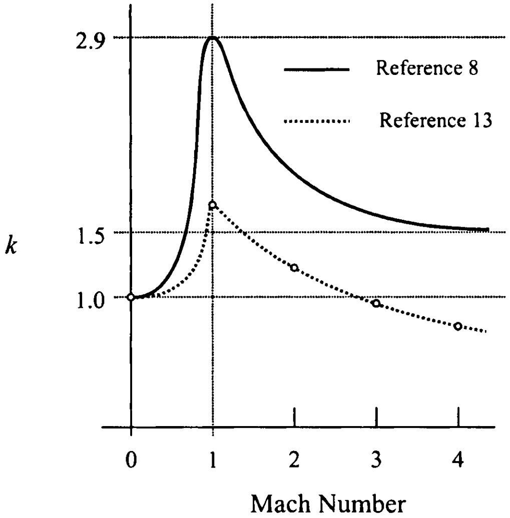


Figure 14–2: Compressibility effects upon the unpowered flight drag.[8]

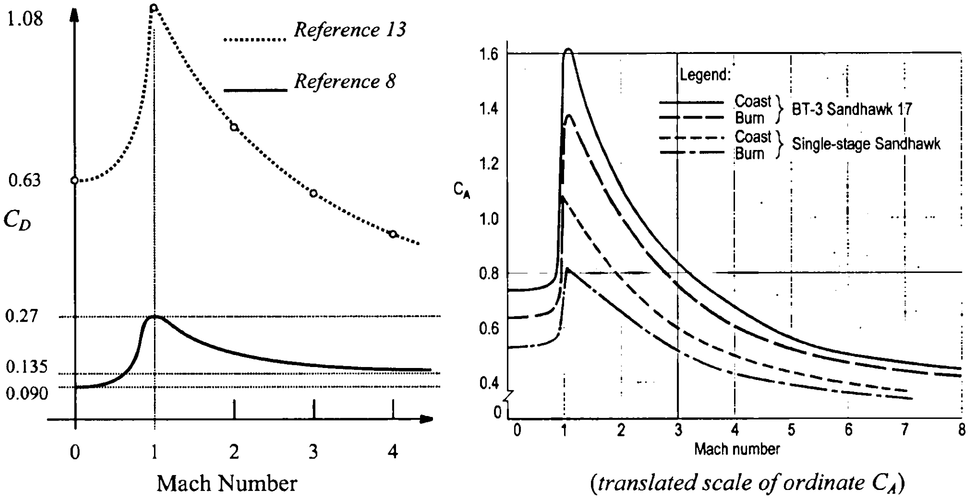


Figure 14–3 : Drag versus Mach number.[8, 13]

First we observe that the drag behavior of the artillery shell is fairly different from that of the rocket fuselage. The first presents a higher drag at supersonic speeds than at subsonic ones, while for a rocket vehicle the ratio is reversed. Overall, the rocket drag is much higher than the projectile drag, around five times higher at mean, due to a better aerodynamics of the former. Experimental data in Figure 14–3 are wind tunnel results for the axial drag coefficient C_A adjusted by radar tracking data from repeated flights, thus quite reliable. At zero angle of attack the axial and the upwind drag are equal. The effect of the angle of incidence is not considered here. We recollect that actually the first sound experimental measurements of drag and lift at various angles of incidence were obtained at Peenemünde by the German rocket team in 1939 in the supersonic wind tunnel up to Mach 5, which was destroyed in the bombardment from August 1943.

Mechanical Efficiency

To resolve the problem of flight efficiency Pavel first proves the formula for the ideal burn-out speed capacity of the rocket vehicle in free space and obtains the known equation of rocket motion $V_b \equiv C\ln(1+M_p/M_b)$. Thus he defines the useful effect of a losses-free space flight as the *energy* E_b *gained by the mass* M_b *of the vehicle at burn-out*:

$$E_b \equiv M_b \frac{V_b^2}{2} = \frac{M_b}{2}\left[C\ln\left(1+\frac{M_p}{M_b}\right)\right]^2 \tag{3}$$

Pavel says that the total consumed energy is the relative kinetic energy of the propellant mass, expelled with the constant exit velocity C:

$$E_p \equiv M_p \frac{C^2}{2} \tag{4}$$

Thus the mechanical efficiency of the rocket flight is more extensively expressed today in terms of velocity ratio $\nu \equiv V_b / C$, but Pavel preferred to perform the analysis in terms of the propellant mass ratio $\mu_p \equiv M_p / M_b$,

$$\eta_e \equiv \frac{E_b}{E_p} = \frac{[\ln(1+\mu_p)]^2}{\mu_p}. \tag{5}$$

The original plot of η_e versus (M_p/M_b) from Pavel[6] is given in Figure 14–4.

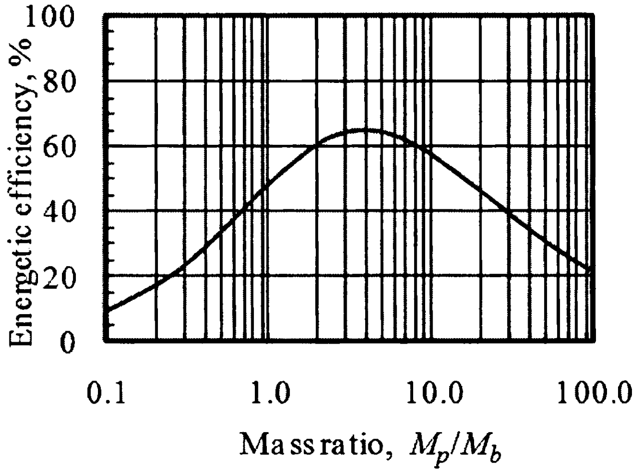


Figure 14–4 : Energetic efficiency after Pavel.[8]

The actual propellant ratio for some existing rocket systems is given in Table 14–1. As far as today the launch mass ratio $\mu \equiv M_p / M_b + 1$ is more largely used, we shall compare the results of different authors with the Pavel result in variables ν and μ:

$$\eta_e \equiv \frac{E_b}{E_p} = \frac{M_b}{M_p}\frac{V_b^2}{C^2} = \frac{\nu^2}{e^\nu - 1}, \qquad \eta_e \equiv \frac{E_b}{E_p} = \frac{(\ln\mu)^2}{\mu - 1}. \tag{5}$$

The comparison of mechanical efficiencies η_e is given in Figure 14–5.

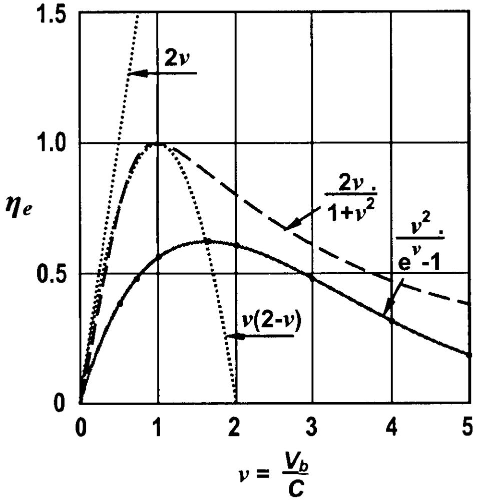


Figure 14–5 : Comparison of energetic efficiency definitions.[8, 15]

The well-known (and strange) maximum efficiency of 64.8 percent appears on setting the derivative of η_e to zero:

$$\frac{\mathrm{d}\eta_e}{\mathrm{d}\frac{M_p}{M_b}} \equiv \ln\left(1+\frac{M_p}{M_b}\right) - 2\frac{\frac{M_p}{M_b}}{1+\frac{M_p}{M_b}} = 0 \qquad (6)$$

when the mass of propellant has to be approximately four times the empty mass of the vehicle:[8, 9, 12, 15]

$$\frac{M_p}{M_b} = 3.998 \cong 4\,, \qquad (7)$$

namely the mass ratio equals 5 and speed ratio is $\nu = 1.61$.

Pavel also reveals that the propellant content can be increased further, with a negligible efficiency decrease, as shown in Figure 14–4. At $M_p/M_b = 6$ for example, the efficiency is still 97.5 percent of the pick and for $M_p/M_b = 10$ is 89 percent off the maximum. The usual values for the mass enhancement of the space vehicles today are rather on the lower side, as it results from the examination of Table 14–1. Its content is derived from the primary vehicle data[14, 15] in Table 14–2. Notation W^* is used instead of V_b and I_v instead of C.

Vehicle (stage)	M_p/M_b	Efficiency loss, percent	W^*/I_v
Agregat-4*	2.19410	94.91	1.16194
SM65 Atlas*	4.04858	99.99	1.61607
Agena-D	2.26568	95.46	1.18367
Saturn-V (II)	2.01161	93.30	1.10190
Saturn-V (III)	1.80952	91.06	1.03223
Ariane-1 (II)	1.86294	91.71	1.05000
Ariane-4 (III)	1.92101	92.36	1.07208
Shuttle (II)*	5.01067	99.13	1.79292
Ariane-5 (Ic)*	4.86351	99.33	1.76864

* single stage or lift-off stages.

Table 14–1: Features of carrier vehicles.

The deviation from the maximal energetic efficiency of 64.76 percent is given in column "Efficiency loss" in Table 14–1, bearing in mind that the parameter M_p/M_b is the main variable for the efficiency. The miss is below 9 percent for all launch vehicles, but carrier vehicles developed at the beginning of the space conquest are entering a somewhat greater miss.

The judgment complies in respect with the ideal speed gain W^*/I_v also (Figure 14–7 and the text below). Lift-off stages (marked with a star) approach the optimum value of 1.6, revealed by Dorin Pavel.[8] For such an ascent flight under gravity however, a more appropriate definition of the efficiency was required and the author did develop it further.

Vehicle type (stage)	M_p, kg	M_b, kg	W^*, m/s	I_v, m/s
Agregat-4	8,930	4,070	2,870	2,470
SM65 Atlas	100,000	24,700	4,525	2,800
Agena-D	6,140	2,710	3,480	2,940
Saturn-V (II)	416,000	206,800	4,650	4,220
Saturn-V (III)	104,500	57,750	4,356	4,220
Ariane-1 (II)	33,030	17,730	2,940	2,800
Ariane-4 (III)	10,700	5,570	4,670	4,356
Shuttle (II)	704,500	140,600	8,000	4,462
Ariane-5 (Ic)	155,000	31,870	7,545	4,266

Table 14–2: Primary vehicle characteristics.

The Dynamic Efficiency

Following a simple approach, at least for short time periods the speed gain in a rectilinear flight with the angle θ above the horizontal is proportional to the acceleration a:

$$\Delta v \sim a = -g_a + \sqrt{a_r^2 - g^2 + g_a^2} \tag{8}$$

where $g_a = g \sin \theta$ was denoted and a_r is the acceleration of the corresponding free-space flight with the energetic efficiency η_e, providing a proportional ideal velocity gain:

$$\Delta W^* \sim a_r \tag{9}$$

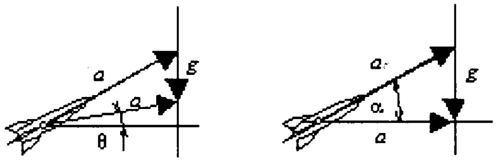
The gravity produces then an extra velocity loss and Pavel assessed it by the dynamic efficiency:

$$\eta_d \equiv \frac{\Delta v^2}{\Delta W^{*2}} = \frac{a^2}{a_r^2} \tag{10}$$

or, taking into account the geometry:

$$\eta_d = 1 - \frac{g^2}{a_r^2} + 2\frac{g_a^2}{a_r^2} - 2\frac{g_a}{a_r}\sqrt{1 - \frac{g^2}{a_r^2} + \frac{g_a^2}{a_r^2}} \tag{11}$$

The rectilinear speed rate is ever lower then the free flight one (Figure 14–5) and this way the vehicle always operates with a definite incidence α in respect to the velocity or to the local horizontal (equigravisphere).



(a) ascent (b) horizontal

Figure 14–5 : Losses due to gravity (Pavel[6]).

Only in a curvilinear flight the centrifugal effects allow for zero incidence evolution, namely for the flight well known as gravity-turn. When the flight direction is preserving horizontal, the dynamic efficiency turns simply into:

$$\eta_{do} = \frac{a_r^2 - g^2}{a_r^2} \equiv 1 - \frac{g^2}{a_r^2} \tag{11}$$

As a consequence it is also shown that a horizontal flight is only possible for values of a_r/g exceeding 1.

During a vertical ascent all three accelerations are co-linear and the dynamic efficiency of the rocket flight becomes:

$$\eta_{d\ \text{vertical}} = \left(\frac{a_r - g}{a_r} \right)^2 \equiv \left(1 - \frac{g}{a_r} \right)^2 \tag{12}$$

Values of the dynamic efficiency in this situation are obviously much lower with respect to the horizontal equipotential flight of same thrust enhancement, as corresponding plots in Figure 14–6 show.

The overall mechanical efficiency of the rocket flight can thus be evaluated with the final formula:

$$\eta_{eg} \equiv \eta_e \eta_d = \frac{M_b}{M_p} \left[\ln\left(1 + \frac{M_p}{M_b} \right) \right]^2 \times \left(1 - \frac{g^2}{a_r^2} + 2\frac{g_a^2}{a_r^2} - 2\frac{g_a}{a_r}\sqrt{1 - \frac{g^2}{a_r^2} + \frac{g_a^2}{a_r^2}} \right) \tag{13}$$

Plots of this global effectiveness are reproduced in Figure 14–6 after Pavel[6] for a horizontal and a vertical flight in outer space with constant gravity.

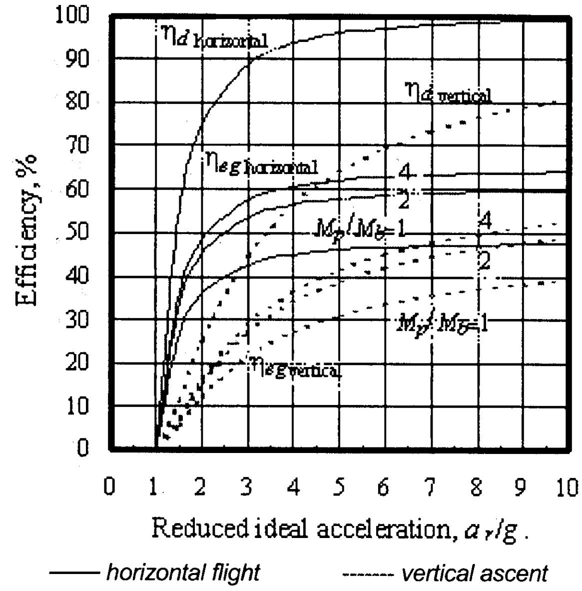


Figure 14–6 : Mechanical efficiency (Pavel[8]).

We observe that relative acceleration values of at least 2 g are needed for the horizontal flight to have a dynamic efficiency of 75 percent, while the same dynamic efficiency figure during a purely vertical, atmosphere free ascent requires boosts of 7.5 g and at thrust enhancements $a_r/g = 2$ the vertical flight is affected by a 75 percent dynamic loss.

The dotted plots in the lower part of Figure 14–6 are global efficiencies η_{eg} computed with formula (13) for a vertical ascent with different values of the propellant content M_p/M_b between 1 and 4, as indicated in the draft. Higher values of this ratio improve the efficiency, as already found, but these values are all below 50 percent and indicate that great thrust enhancements are to be used. This was seen already in 1929 by Pavel as clear evidence that the vertical evolution in a gravitational field is inefficient and must be avoided as possible.

The global mechanical efficiency versus thrust is also given in the drawing for the horizontal flight when M_p/M_b varies between 1 and the best value of 4.

The figures are higher than for the vertical ascent but we are also told that important propulsive trajectory arcs with near horizontal direction, for orbital acceleration in particular, are somehow inefficient.

At the same time, the rectilinear flight under different angles is affected by efficiencies between the two limiting cases. It is usual at present to describe the energetic efficiency of rocket flight with the speed as the variable, specifically the speed of flight rated to the vacuum specific impulse W^*/I_v. The author presented this discussion in Figure 4 of his article[8] (Figure 14–7 of present chapter) and this looks quite identical, for example, with the one in Figure 2.2. of the book by Messerschmid,[15] published in the year 2000, with the difference only that the mechanical efficiency is termed as "external efficiency" of the rocket system.

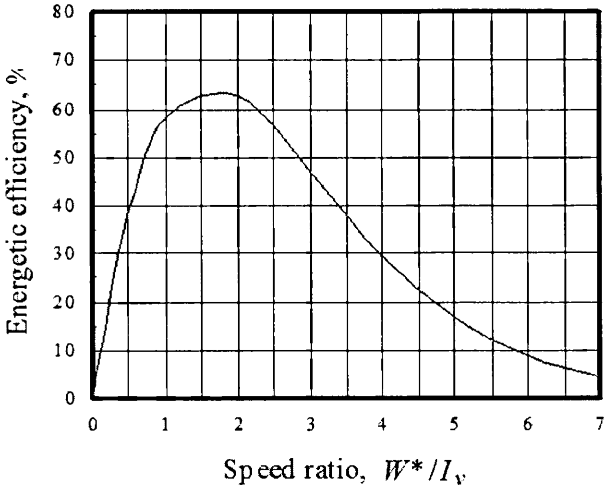


Figure 14–7: Energetic efficiency after Pavel.[8]

The best known value of 1.6 for the speed gain is thus deduced by Pavel. He recommends flying speeds between 0.8 and 2.8 of the vacuum specific impulse. This observation is used by Pavel to emphasize on the utopian attempts of Max Valier and others to use rocket propulsion for terrestrial applications in the 1920s.

Conclusions on Efficiency

The conclusion of Professor Pavel's theoretical approach in respect to the mechanical efficiency and optimum flight conditions reads that the optimum ascent problem into an atmosphere is a difficult yet unsolved theoretical challenge. He gives the approximate formula of Oberth for the best climbing speed as an example of the difficulties. In that respect we must notice that the problem, as announced by Goddard in 1919, of optimal rocket flight, had been formulated by Georg Hamel[16] only two years before the article of Pavel was published. Although the Hamel formulation was made in strong variation terms, it was incomplete in respect to the discontinuity of the functional at burn out. Intriguing is that the actual discontinuous variation problem of the best atmospheric ascent was completely solved only today, 70 years after the first enunciation when the new variation technique of multiple deviators was developed.[17]

Altitude for a Long-Distance Flight

Recognizing the Arrhenius density of air distribution with altitude, Pavel made comparative computations of the required power when motor-propeller engines of classical type and rocket engines are used (Figure 14–8).

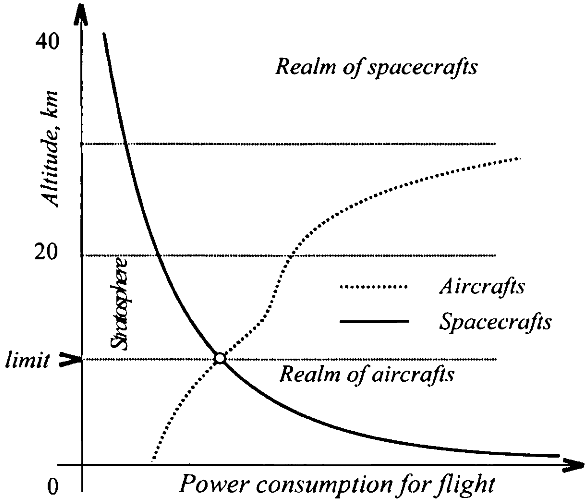


Figure 14–8: Limit for the realm of aircraft.[8]

Dorin Pavel concludes that the limit of the efficient aircraft flight is at 10 kilometers altitude and above this limit the rocket propulsion system is better suited for long-distance flight. The upper limit for air-breathing flight had risen up to present to almost 30 km, but essentially the situation has not yet changed, despite the efforts endeavored to use the air-breathing propulsion systems up to the threshold of space. The "space-plane," first desired by Dorin Pavel and long waited is still a project, 73 years after it was detailed by Sänger.

The Propellant

On a simple and purely energetic basis, typical for the early works in rocket propulsion, where the enthalpy difference *E* among the combustion products and the reacting propergols (as termed by Pavel) was taken into account, the author lists some five liquid-state propellants in the chemical systems Cl-O-C-H and O-C-H. The obviously superior combination LOX+LH_2 is especially analyzed in respect with the relative ratio of oxygen and hydrogen. It was found that an exceeding molar content of hydrogen of between 50 percent and 150 percent above that of the complete-burn ratio is best suited to deliver a maximal exhaust velocity, as reproduced in Table 14–3.

Propellant, moles	H_2 surplus, percent	Bulk density, kg/cm	T_{max}, °K	I_v, m/s
2 H_2+O_2	0	0.423	6,650	4,535
3 H_2+O_2	50	0.334	4,718	4,718
4 H_2+O_2*	100	0.281	3,930	4,725
5 H_2+O_2	150	0.246	3,275	4,718
6 H_2+O_2	200	0.221	2,820	4,710
8 H_2+O_2	300	0.188	2,180	4,560
12 H_2+O_2	500	0.151	1,510	4,315
22 H_2+O_2	1,000	0.116	850	3,700

* Optimum value.

Table 14–3: Efficiency of LOX+LH_2 by Pavel.[8]

With respect to the pressure level in the combustion chamber, Pavel agrees with a rather reduced value of 20–30 atmospheres (atm). This range shortly proved realistic and was largely used in the early phase of rocketry, especially on the side of Western technology, mainly due to the combustion stability aspects.

The author Dorin Pavel was reluctant regarding the value of 100 atm advanced by Oberth. We know today that the Soviet technology approached, since 1950s, this option in the development of most of the liquid propellant rocket engines (LRE) for ground launch, including the famous RD-107 and RD-108 motors, still in service today with the Soyuz transporters. Pressures of up to 270 bar in the combustion chamber are commercially used in the RD-170 engines that equip the Atlas-5 family today, while the first large reusable LRE for the space shuttle are working at 200 bar of pressure in the combustion chamber.

Conclusion

Pavel makes very interesting observations relative to suspected physiological aspects of spaceflight. An aircraft pilot himself during his free time, the author believed that overloads of up to four times that of gravity produce no harm on "future" occupants of spacecrafts. New researches for that time are recollected which show that variation of acceleration is possibly more harmful than the acceleration itself. Anyhow the author thought that the start and return of spacecraft should not be a pleasure trip and will have required special training for the astronauts. All these presumptions eventually proved valid.

Pavel relates his own experience on running in the centrifuge at the University Göttingen in Germany, where he endured unpleasant sensations on a constant centrifugal effort of 2 g only: recollect that all happened in the year 1927!

At the end of the article Professor Pavel advances an exceptional call for the continuation by the Romanian authorities of the work in astronautics opened by Oberth.

> We are on the brink of a new era and believe, that the great mathematician Fr. Gauss was right on saying that applications of the principle of reaction should be of more importance than the discovery of America: this without annoying our friends from over the ocean. Despite the whole endeavor of inventors, we are at the beginning of investigations and believe that as long as partial problems are not studied with high means, theoretical and empirical, nothing serious would result. It seems that specially created institutes by Russians and Germans had undertaken serious initiatives. (Pavel, 1929)[8]

It was only after World War II that his forecast had proven accurate.

This remarkable article was submitted for publication on 15 November 1929 at the "Politehnica" University in Bucharest. Despite the terrifying political circumstances, in 1962 the first Romanian experiments on liquid rocket engines took place, at the same "Politehnica" University, unfortunately not sustained by authorities.[18] What followed in the years that passed since the publication is now a matter of proven history, to only recollect for short:

- humans in space after only 32 years,
- a man on the Moon in a mere 40 years, and
- robot flights into the whole solar system and beyond.

The next goals: "humans on Mars" and the space-plane. Here we are, thanks to the visionary dreams of the army of famous forerunners worldwide, like the distinguishable Romanian Professor Dorin Pavel.

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