NON-EUCLIDIAN ECONOMICS

The title sounds absolutely absurd since neither Euclid, nor Lobachevski, were ever involved in economics, and such a title for the article could only have been dreamed up only by a person who is not familiar with the works of these outstanding scholars. Yes, I must confess that I have never read a single work by either of them. But by intuition I feel that the same way that the Euclidian postulate on parallelism presents a special case of Lobachevski differential geometry, the economics, which we were taught at higher educational establishments, is not as rectilinear as it may seem to be at first sight.

Can one catch elusive happiness?

Each human being possesses his or her formula for happiness. For some people it is enough to love and to be loved; some people need a lot of money in order to feel happy, the third group would like to be involved in a labor which they love irrespective of any monetary reward, a love sufficient that nothing could prevent them from pursuing their labor of love. I assume that many "General Aviation" (GA) journal readers would like to construct and/or fly without thinking too much where to get money for their dream. It was more or less the same situation in the Soviet Union, when each resident of the country, willingly or unwillingly, surrendered part of their income through compulsory contributions that made the Soviet aviators (air cadets) feel financially worry free.

Alas, those days have passed away.

I would not like this article to have nostalgic, and even less so, ideological shades. To be fair, one could recollect that before 1978-79 in the USA there were many happy people able to fulfil their dreams, for instance in private aviation. But due to an energy crisis within the five subsequent years GA aircraft production in that country suffered a nine-fold drop, and remained at that level until the next recession in 2008 [1]. At the beginning of the eighties thousands of Americans not only lost their ability to access aviation, but in general remained without any discretionary income. Many thousands lost the opportunity to exercise their love for flying.

Thirty years later the situation has recurred. What is interesting is that exactly as it was in the eighties, when the market for the ultralight aircraft started taking shape, nobody had any clue about the forthcoming crisis in GA. These simple flying vehicles apparently were losing out then and are losing out nowadays to light aircraft offering better performance. Their apparent simplicity is why, presumably, initially not too many people paid attention to ultralights.

But in the time of financial crisis the people, striving to live within their means, when faced with the alternative of whether or not to fly at all, or to switch to something more accessible but less sophisticated, many people choose the latter. Today we can assert that making that choice is still the how the people of the world react.

Specifically when the Soviet Union disintegrated, flying these aircraft proved to be too expensive here also. Many a man thought that the solution to the cost problem lay in the production and proliferation of cheap ultralight flying vehicles (UFV). But after two dozen years ultralight aircraft are a rare sight in the Commonwealth of Independent States' (CIS) skies, aircraft about which aviation enthusiasts have long dreamed, and which were eagerly awaited. And as it was in the USA thirty years ago, thousands of people in the CIS today are not able to exercise their love of flying, particularly not in the more expensive UFV now on the market. What is the prospect for the future?

Not the baker's business

About six years ago one outstanding Ukrainian politician, a well-educated many-sided man who in his young years pursued science, told me that there is no fundamental difference between the baker's business and aircraft manufacturing: they are governed by the same economic laws. It is difficult to argue with such a conclusion in general, but if we speak about the particulars it is impossible to agree. Unfortunately the discussion which broke out was never ended, since we met only one or two times, and my antagonist left this world too early. But the comparison, which I heard several years ago, penetrated my mind so deeply that I have not been able to shake the analogy presented by my friend.

Let us together inspect the photograph in the title. On the background there is a wooden cart – the transportation means of the remote past. In order to produce it, the craftsman required simple tools, some wood and few metal parts, produced at the neighboring blacksmith shop. And now let us shift our gaze to the foreground. What hits the eye first of all? Air propeller, wheels, comfortable seats, engine, muffler, fuel system, storage battery, covered by cowl panel, instruments, electrical system elements, steel pipes, braces made of aluminum alloy, wing skin material ... All these items need to be purchased from distant sources in order to construct this vehicle, which is relatively simple by aviation standards.

In the large aircraft fleet from 70% up to three fourths of modern aircraft the basic cost includes material cost for purchased integral parts (PIP) and materials (Fig.1). More than that, because all these items have to be purchased, there is no practical way to influence the prices of these purchases, since the number of suppliers of integral parts and materials in aircraft engineering have always been and will be less than the number of the enterprises for final assembly of the flying vehicles.

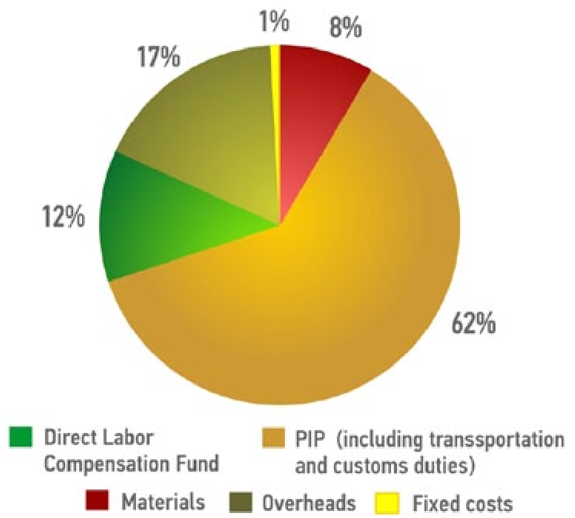

Fig. 1. Prime cost structure for regional jetliner

The structure of GA aircraft is such that the basic cost depends on complexity demanded by higher performance: the higher the performance, the bigger the share of material costs, and principally the PIP share. But it does not mean that the cost of purchased integral parts, PIP, will be small in the production of modern ultralight aircraft, or in production of Light Sport Aircraft (LSA). For example the price for a glass cockpit alone on the basis of a GARMIN G500 PFD – digital flight-navigation instrument, which nowadays is installed on two-seater LSA category aircraft, costs more than 30 thousand Euro (at that rate the price for G500 amounts $15,000 US). The engine, a Rotax 914 UL with 115 h. p. already costs more than $33,000 US. Not long ago for the same amount of money it was possible to buy the complete aircraft. Thus, LSA are far ahead as a primitive transportation means and, figuratively speaking, now are much closer to an A380 than they are to an antiquated wooden cart.

However, this example illustrates well-known truths for "GA" readers. If only we could know in which way LSA will change, how far the prices will go up, and what the consequences will be of all these factors. Maybe we could manage "to put some straw" to dampen the shock when their popularity begins falling.

Let us try and do it together.

With seven-leagued steps towards the crisis

Twenty years ago serial production of very light aircraft (we unite under this term both ultralights and LSA) was only at the beginning. That recent beginning made it impossible to collect statistics enabling us to estimate which way their pricing would change. But even then it was quite obvious, that under the existing market conditions it would be beneficial to examine pricing structures. One of the first ideas which appeared was the idea to link cost indicators with aircraft performances. And nowadays, by the way, many aviation market researchers try to apply similar models. Similarly, we at the Board for Aircraft Design of Kharkov Aviation Institute decided to construct several regression models [2]:

$$P_{4s} = 1{,}161 \cdot 10^{-3} \cdot V_{cr}^{0{,}612} \cdot L^{-0{,}3867} \cdot m_0^{1{,}9489} \cdot N_0^{0{,}1386} \cdot l^{4{,}6654} \cdot l_f^{-3{,}9023}, \qquad (1)$$

where P_{4s} – price of four-seat, single-engine GA light aircraft, USD;

V_{cr} – cruise speed, km/h;
L – flying range, km;
m_0 – maximum take-off mass, kg;
N_0 – maximum take-off power, kW;
l – wing span, m;
l_f – fuselage length.

$$P_{2e} = 0{,}555 \cdot N_0^{1{,}13} \cdot m_0^{-0{,}015} \cdot m_{empty}^{0{,}063} \cdot m_F^{0{,}188} \cdot V_{cr}^{-0{,}107} \cdot L^{-0{,}11}, \qquad (2)$$

where P_{2e} – price of twin-engine GA light aircraft, thousand USD;

m_{empty} – empty aircraft mass, kg;
m_F – fuel mass, kg.

The first model was constructed on the basis of the sample from 89 elements, the second one included 32, thus we manipulated with statistically significant arrays of information. And mathematical methods for processing the data were well-defined. That is why the computation results satisfied everybody. But that calculation was for the time of 20 years ago. Let us apply the same formulas for today's situation.

If we substitute the data for modern four-seat single-motor light aircraft in (1): V_{cr} = 287 km/h, L = 1482 km, m_0 = 1280 kg, N_0 = 124 kW, l = 11.63 m, l_f = 8.06 m we arrive at an estimated price of $132,889 US. It is exactly its price twenty years ago, but today at this price it is possible to buy only well-stocked two-seater LSA. By the way, if we return to more remote past, we will see, that hypothetical light single-engine and six-seat aircraft with take-off mass of 2339 kg

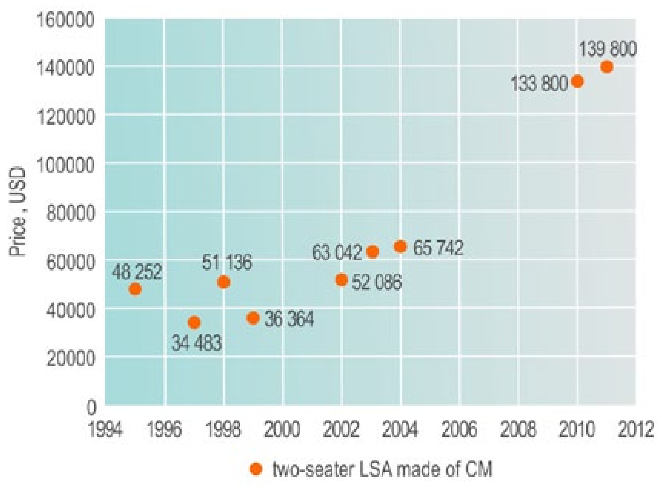

Fig.2. Price change for two-seater LSA made of CM [5-14]

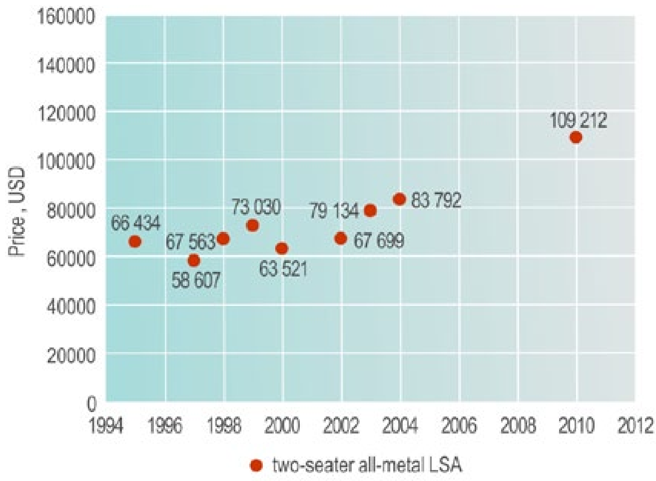

Fig.3. Price change for two-seater all-metal LSA [5-14]

in the mid seventies was priced in the amount of $108000 thousand US [3]. In 1983 the price of real serial six-seat A36 Beech Bonanza was equal to 135 thousand USD [2], and in 2006 aircraft G36 Beech Bonanza with the same engine with power 210 h.p., but fitted with «glass cockpit», was already offered for 459 thousand USD [4].

Let us calculate the price for four-seat twin-engine GA aircraft according to formula (2) using the following parameters: N_0 = 334 kW, m_0 = 1900 kg, m_{empty} = 1415 kg, m_F = 151 kg, V_{cr} = 287 km/h, L= 1315 km. We arrive at a cost of $253,000 US. Today the bench-mark price for one of the cheapest representatives of this family exceeds 300 thousand Euro (more than $ 430,000 US), It appears that our calculation is out by more than a factor of 2.

But let us come back to our research. What has happened? Twenty years ago, as it was noted then, research was made at a high scientific level with application of computers, but the result turned out to be nondurable. Perhaps the formulas could be applicable for a two year period, but then they became obsolete very fast. At that we should admit, that many aircraft, which in those days were included in the samples for construction of regression models, are still flying, and some of them are still being manufactured. Since then their flying performances changed very little, or in general remained unchanged, but nevertheless the prices grew several times. Hence, it is not the performances factor which is the main reason for such quick rates of price change for light aircraft and aviation equipment in general. But the prices do rise, so what is the underlying cause of this growth?

Today, twenty years later, when we try to find the answers to this question, there is already an opportunity to trace price changes for very light aircraft, first of all for ultralights but then also for LSA, on which many people had put their hopes after the first world crisis in GA. We will use data from annual catalogues known today as World Aviation Directory of Leisure Aviation [6–15]. On Fig. 2 and 3 the examples indicate price trends over time for representatives of the LSA family: two-seater high wing aircraft made of composite materials (CM) and all-metal low wing aircraft. Both aircraft types use the Rotax 912 UL/ULS engine and an increase in take-off mass from 450 kg up to 472.5–600 kg is in compliance with altered certification requirements. The differences between the aircraft are clearly demonstrated on the graphs.

One should note that in some catalogues of 1995–98 the prices are specified in Francs, German Marks, or Italian Liras. Today when we quote them in USD according to exchange rates of that time, we involuntary make errors, since we not only do not know for sure which exchange rate was used by the catalogues authors, but we also have no idea which price was specified: manufacturer's or dealer's. In any case, the prices quoted in USD for practically all the articles included in the catalogues of the first years of publication are higher than the prices in the mid nineties. But later the tendency to growth was stable.

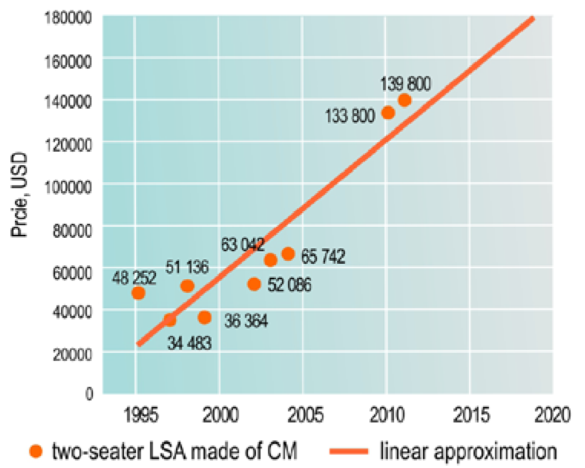

Fig.4. Price forecast for two-seater LSA made of CM by 2020

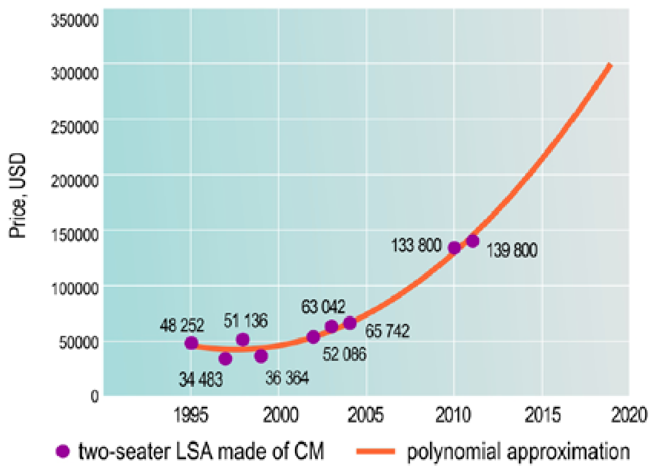

Fig.5. Price forecast for two-seater LSA made of CM by 2020

As we can see, the price for high wing aircraft in 2011 turned out four times higher compared to the price in 1997. Price growth for low wing aircraft was more moderate – less than two times. But the tendencies for growth coincide.

Using mathematical statistical methods, let us construct trend lines and corresponding analytic dependencies. As we see from Fig.4 and 3, the price for two-seater high wing aircraft made of composite materials in 2020 could exceed $180,000 US (at Y = 2020 P_{2hl} = $180,012 US)! A correlation ratio r = 0.92 shows a high statistical significance of such a forecast.

$$P_{2hl} = 6548{,}7 \cdot (Y - 1995) + 16294, \qquad r = 0{,}92 \qquad (3)$$

$$P_{2hP} = 549 \cdot (Y - 1995)^2 - 3711{,}4 \cdot (Y - 1995) + 48149, \qquad r = 0{,}99 \qquad (4)$$

The statistical significance of the polynomial approximation is higher (4): r = 0.99. But the price for LSA according to such a forecast will jump to $300,000 US ($P_{2hP}$ = $298,921 US) by 2020! And not much time remains till 2020 – 8 years ahead. How well we remember 2004, which is within the same 8 year time span. Frankly speaking, I do not want to trust any of these forecasts, and abstract statistics are not very convincing. But if this forecast should come true, the LSA market will suffer a collapse, since it is unlikely that there would be very many people willing to pay one third of a million dollars for such aircraft as the LSA, even eight years from now. Obviously, it is worthwhile to seek out more adequate models of prediction.

Maybe the inflation should be blamed for everything? This is pretty easy to verify by means of inflation comptometers, which are available in plenty on the Internet, for instance on the site of the Ministry of Labor of the USA [17]. Let us see what the projected price for today's two-seater high wing aircraft made of Composites, the price of which in 1997 amounted $34,483 US. One comptometer yields $48,328 US. The other one, more accurate, which takes into consideration more expensive labor of skilled manpower in 2010 – $50,300 US, and, considering the anticipatory profit – $52,900 US [18], but not $139,800 US [16]. For all-metal low wing a/c the price within the same period due to inflation might go from $58,607 US up to $82,137 US [17], and according to the more accurate comptometer – up to $89,900 US [18]. But not up to the $107,371 US, quoted in a recent catalogue [16]!

Naturally, inflation is one of the reasons for price growth for the aircraft in general, and in this case LSA are no exception. But inflation is not the only reason. And if these reasons are not revealed, uncontrolled prices growth will really lead to the same crisis, as the one which occurred at the end the seventies in the USA, and in the Soviet Union at the beginning of the nineties.

One beats the bush and seven others catch the bird?

Maybe, the reason, first of all, lies with the owners of the aviation companies, striving for excess profits, and ruthless exploitation of hired workers? But, judging by the number of bankrupted aviation firms, it is hard to believe that may be happening.

Since the problem is of an economic nature, we will try to analyze it according to economic elements.

Let us return back to the seventies. Then according to evaluations done by specialists of company the Beechcraft company the cost of materials of the airframe of light six-seat aircraft amounted $11.9 US/kg, on-board systems equipment (not including avionics) – $29.4 US/kg, piston engines with power range about 200 h. p. –$ 41 US/kg, avionics – $187.5 US/kg. In the example, which was considered in [3], prime cost of six-seat light aircraft was evaluated in the amount of $89,820 US.

If we analyse the manufacturing cost of the primary structure of that aircraft according to the diagram (Fig.6), we will see that it differs from the basic cost of the structure of a modern passenger airliner. Beechcraft's PIP share is less, overheads are higher. Though, with respect to direct labor compensation fund (DLCF) they constitute only 206%, but not 750-1000% as at many serial aviation plants in the Soviet Union today. It is quite possible that overheads for manufacturing of light aircraft at aviation plants in the USA in the seventies were higher than at modern small LSA manufacturers. It is interesting that in the example made for the middle of the seventies, labor cost was taken equal to $5 US/man-h., in the USSR at the beginning of the eighties it was equal roughly to 0.8 Ruble./man-h., i.e. more than six times lower. But we will return to that later.

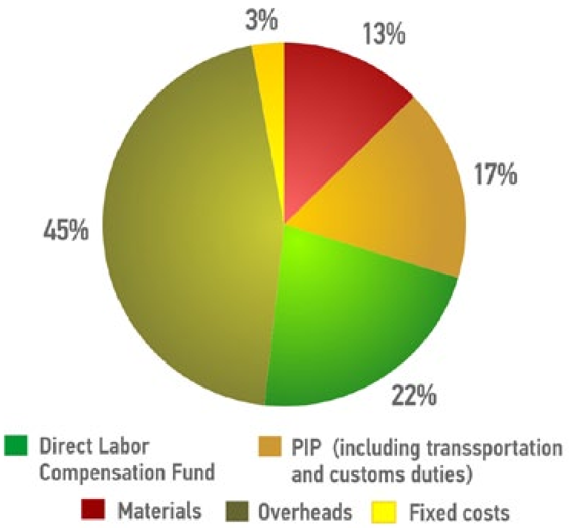

Fig. 6. Prime cost structure for light aircraft in the middle of the seventies [3]

Let us try to evaluate basic cost for the manufacture of modern LSA, although hard reliable numbers are not available. We will start from the PIP cost, in particular engines, and we will do it using the same catalogues – Leisure Aviation [7–16]. On Fig.7 the change in unit cost for several four stroke piston engines is specified. Nowadays such engines are often installed on two-seater aircraft. Their power does not exceed 115 h.p., and unit costs grew up to $287 US/h.p. in 2011. Let us recollect example [3], where the unit cost of the piston engine was equal to $41 US/h.p. in the seventies of the previous century. If we take 1976 as the reference point, then within 35 years the unit

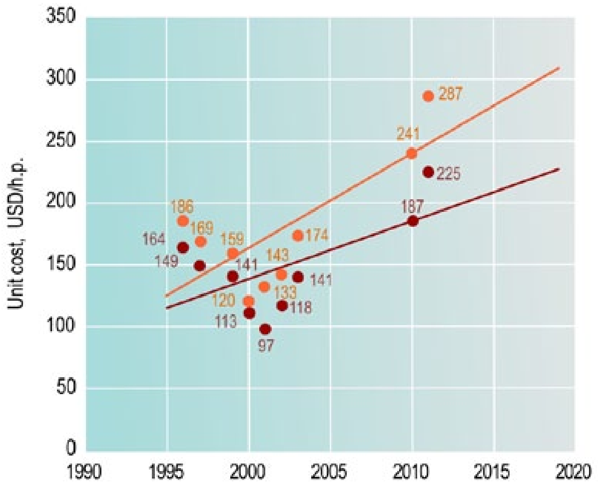

Fig. 7. Change of unit cost of piston engines [7–16]

cost indicator grew seven times. In reality it changed much more, since unit costs of more powerful engines as a rule are higher. Due to inflation the price within that period rose not more than four times. If we evaluate cost increases of one of the most powerful engines being installed today on LSA, then we will see that its unit price within 35 years increased by 20% on average annually. Approximating the trend of its unit price growth by linear relation, we get, that by 2020 this indicator will go up to $309 US/h.p. Using the power approximation will give us an even higher indicator – $321 US/h.p.

Comparing LSA prices with the prices of the engines being installed on them, we see that the cost of the engines' share, without accessories, has increased 1.5–3 times compared to their share in the middle of the 70-ies, and today engines constitute 12–24% of the total basic cost.

Typical of the past decade is the massive introduction of digital flight navigation instruments in private aviation. Today not only on fighter, jumbo jet, light aircraft and helicopter, but also on LSA and ultralights one can see digital units, called 'glass cockpit' in the West. Since specifications and prices for these components appeared in Leisure Aviation catalogues only after 2009, only two samples were available so that it is impossible to present price change tendencies in graphic form. But, having investigated product of 16 companies represented by 35 digital units, we discover that the price range lies from $1,519 US up to $30,000 US, even if we disregard the most expensive systems - Garmin 1000. On a per-kilogram basis of the instruments' mass, the average price in 2010 amounted $3,155 US/kg, and by 2011 it grew by 19% to reach $3,740 US/kg. It seems that there is no special sense in comparing these indicators with the unit cost of avionics of the 1970s ($187,5 US/kg [3]). It is obvious, that the price growth is gigantic. One could argue and say that the age of cheaper analog instruments has not finished yet, and in figurative meaning we should not compare the horse with the fallow deer. I do not mind. Nevertheless if we look into the future, it is difficult to imagine a flying vehicle equipped more primitively than is a standard car. Certainly one can expect that the prices for digital units will drop, as we see it in mobile communications and household appliances. But, agree, that aviation instrument sales will never be as massive as mobile telephones or automobile navigators.

Unfortunately reference books, which could make it possible to trace prices changes for aviation materials applied in LSA, were not at hand. We can get some impression of what the trend is if we assume, that, compared with the seventies and even the beginning of the nineties, composite materials are used more and more in the design of these aircraft. For example in 2008 glass fiber manufactured in the Soviet Union cost on average $10 US/kg, carbon fiber – $30 US/kg, binding agent (vlorite) – $30 US/kg. Taking a correlation between reinforcing elements and binding agent as 1:2, we get, that three years ago 1 kg of glass fiber cost on average $23 US/kg, carbon fiber – $30 US/kg. It is not a large increase compared with $11.9 US/kg in the middle 1970s, but nevertheless more!

Investigating change of the prices for materials and purchased integral parts, PIP, which are used in the for manufacte of modern LSA, we should point out that the tendencies are close to big aviation, where the materials become more expensive on average by 6% annually, and PIP– up to 20%, though the prices for digital units do not fall under this statistic.

When evaluating manufacturing prime cost we can not go without calculating the labor-output ratio. At each modern enterprise its value presents a commercial secret, which is safeguarded with some degree of diligence. Only from very few and scattered publications we can learn, for instance, that of labor-output ratio of N aircraft in the series of two-seater aircraft, made of composite materials, was equal to 4082 man-h, and for four-seat single-engine – 5787 man-h and for the 412-th production aircraft in the series of a four-seat twin-engined aircraft made of composite materials – 7948 man-h [6]. Or, according to the data [19], the ratio of labor to output of four-seat aircraft, produced in series, according to industry regulatory documents of the Soviet Union was equal to 7300 man-h, and in one of the projects LLC «Informtechavia» managed to sqeeze to 2100 man-h, while during the manufacture of Cessna 172 this indicator was two times lower.

In reality the labor-output ratio is the indicator which is ever changing in the process of manufacturing: the bigger the number of aircraft produced, the lower its value. But specific indicators of labor-output ratios lie within quite narrow boundaries. For example, I dare to state, that specific labor-output ratios for many passenger and transportation aircraft, which were under construction in the USSR and during the post-soviet time, lie within the range from 2.94 man-h/kg up to 24.98 man-h/kg. At this the labor-output ratio matches up with airframe mass or empty aircraft mass. Bigger values correspond to the first aircraft assembled at the place of production and lower ratios – toward the final stages of serial production.

If we address the American statistics of the middle of the seventies, we find similar indicators: 22.1 man- h/kg for the first aircraft, and 2.4 man-h/kg for the hundredth [3]. Change of labor-output ratio in the process of aircraft serial production is usually described with the following correlation:

$$T_N = T_{1\,ser} \cdot N^{-\beta}, \qquad (5)$$

where TN – labor-output ratio of aircraft N production in series, man/h.;
$T_{1\,ser}$ – labor-output ratio of the first serial aircraft, man/h.;
N – aircraft number in series;
β – degree indicator, which characterizes intensity of decrease of labor-output ratio.

For example, β = 0,322, assumed in [3], is typical for aircraft manufacturing plants where 75% of labor-output ratio fall under the assembly work, and 25% – to mechanical processing. For engine manufacturing plants, where assembly works constitute roughly 20% of total labor-output ratio in engine production, more typical is the drop of the labor contribution by 10% when the production volume doubles, the reason for the difference in the indicator value.

Let us consider a program for LSA manufacturing which corresponds to a small enterprise: 60 aircraft a year are in commercial production. At this, in future all the indicators concerning labor-output ratio, prime cost and price will be defined for medium serial number of the aircraft in the year concerned. If within the first two years only nine aircraft were assembled (three in the first year and six in the second year), then the median serial number of the aircraft in the second year of production will be 6, and in the last year, when 753 aircraft are assembled, the median serial number will be 723 (Fig.8).

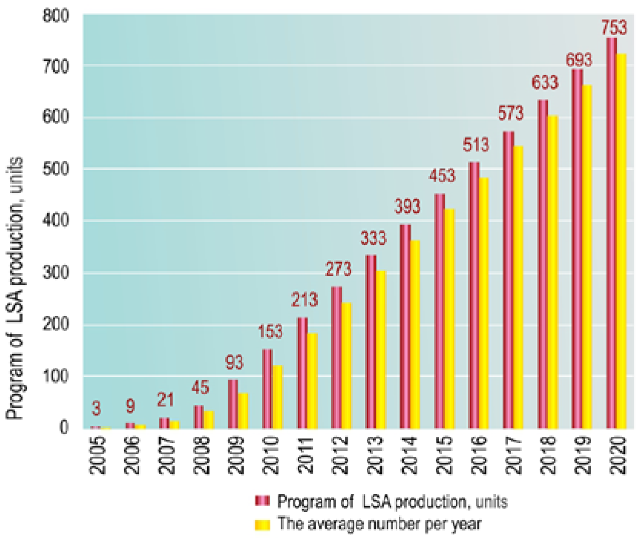

Fig. 8. Program of LSA production

Since not only each company, but each aircraft project has its own peculiarities, for precision of evaluation of basic cost of a hypothetical LSA, we assume that its airframe mass is 280 kg. We also assume that the specific labor-output ratio of the first serial aircraft is equal to 17 man-h/kg, which corresponds to 4760 man/h. Subsequent labor-output ratios will decrease according to formula 5 at β = 0.322 (Fig. 9):

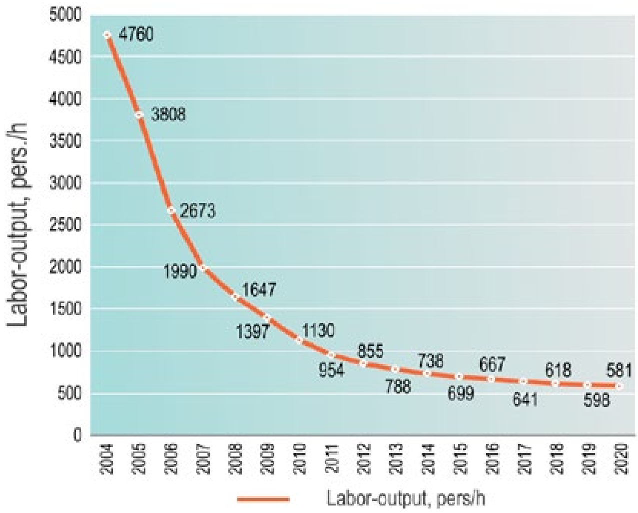

Fig. 9. Change of labor-output ratio in LSA production process

In accordance with the calculations, specified in the above example, the labor-output ratio in the LSA production process decreases from 4760 man/h, during assembly of the first aircraft, to 571 man-h during production of the 753-rd aircraft.

For this calculation the annual working time allotment of one full-time production worker is assumed to be 1693 h/year (168 h/month at 16% time loss) and with the changing labor-output rations (Fig 9) an increase from 7 up to 36 persons will be required (Fig. 10) for accomplishment of the production program.

Fig. 10. Change of direct production workers staff

How to correlate aircraft manufacturing basic cost with labor-output ratio and material costs and integral parts? In [4] I suggested to do it by means of a simple correlation:

$$C_{tot} = C_{PIP} + C_m + C_{be}\ , \qquad (6)$$

where C_{tot} – total prime cost of aircraft manufacturing (USD);
C_{PIP} – cost of purchase of integral parts, including engines (USD);
C_m – cost of materials purchase (USD);
C_{be} – business expenditures (USD).

$$C_{tot} = C_{PIP} + C_m + c_{be} \cdot T, \qquad (7)$$

where cbe – specific cost of one man/h of direct labor, USD/man-h;

T – total labor-output ratio for aircraft production, man/h.

value BE could be defined according to the following dependence:

$$c_{be} = W_{DPW} \cdot k_{be} = W_{DPW} (1 + K_{EW} + K_{PT} + K_{GPO} + K_{AO} + K_{CIEP} + K_{UC}), \qquad (8)$$

where W_{DPW} – cost of man-hour of direct production workers.

$k_{be} = 1 + K_{EW} + K_{PT} + K_{GPO} + K_{AO} + K_{CIEP} + K_{UC}$ – business expenditures ratio;

K_{EW} – extra wages ratio;

K_{PT} – payroll tax ratio;

K_{GPO} – general production overheads ratio;

K_{AO} – administrative overheads ratio;

K_{CIEP} – ratio of costs increase for equipment production and preproduction procedures;

K_{UC} – unproductive costs ratio.

Each particular country has its own specific payroll tax ratios (deductions to social funds). For example in Russia it constitutes 30%, in Ukraine it constitutes 38.5%. That is why ratio KPT can acquire values 0.3, 0.385 depending upon the existing laws. In order to stimulate direct production workers, extra wages, additional to the basic salary, could increase up to 60% within the period of active work, and drop down to 25% during idle periods. Overheads, which include rent costs and permanent structures maintenance, maintenance of equipment, charges for energy, including electric power and other costs, related to the direct labor compensation fund, vary within a wide range. The same concerns administrative staff costs, defined by KAO, unproductive costs, mostly connected with marketing, sales and in-operation maintenance, which also vary. I have already mentioned that at modern aircraft manufacturing plants with a reduction in the number of direct production workers and preservation of the existing infrastructure k_{be} = 7.5–10.0 (750–1000%). At Beechcraft manufacturing plants for production of light aircraft in the middle of the seventies k_{be} = 2.06 (206%) [3]. It would be instructive to perform some parametric calculations, taking different overhead ratios from 200% up to 1000% and even use their variation according to certain correspondences.

But, before we pass to calculations, I should note that correlations (6)–(8) reflect the situation corresponding to a sustainable, and I may say, ideal production process. Indeed, only in theory can one imagine that the prices for integral parts and materials do not change, the wages of all employees categories remains stable, and that there are no idle periods. In the real world all the above mentioned features do exist, and that is why it will be more correct to present the correlation (6) in the following form:

$$C_{a/c}(t) = C_{mat}(t) + C_{PIP}(t) + c_{be}(t) \cdot T(t) + c_{idle}(t)\ T_{idle}(t) / N_{year}, \qquad (9)$$

Firstly, all the components depend on a time factor (Fig. 7, 9). Secondly, in reality idle periods occur due to various reasons, but mostly due to lack of orders as, for example, during certain crisis periods.

This correlation, analogically with business expenditures, should be complemented with expenditures for idle periods (idling cost) $C_{idle}(t) = c_{idle}(t)\ T_{idle}(t)/N_{year}$. You will hardly find such a prime cost component in any textbook on the economics of the aviation industry, since in theory an idle period should not exist. But in practice they do exist. By analogy with labor-output ratios the value $T_{idle} = t_{idle}\ n_{DPW}$ will be entitled idling capacity, which is measured in man-h: the more idle periods are experienced, the bigger is the loss in capacity. In this case t_{idle} – idling period of direct production workers, expressed in hours, n_{DPW} – number of idling workers (people), and N_{year} – annual production program during idling periods.

During an idle period there is a reduction of $c_{be} = c_{idle} = W_{DPW}\ k_{be} = W_{DPW}(1 + K_{EW} + K_{PT} + K_{GPO} + K_{CIEP})$, because at a constant tariff rate per unit $K_{EW} \le 1$. As a rule, during idle periods direct production workers do work which is not connected with aircraft production, or they are transferred to the other sites. In particular, they could be targeted to produce equipment and fittings for future manufacturing processes, which could lead to an increase of K_{CIEP}. During idle periods there might be reduction in energy consumption and in other elements of general production expenditures down to the level required to maintain operative ability of the fixed assets. That is why K_{GPO} during the idle periods vary. But since it correlates with the Direct Labor Compensation Fund, which is subject to reduction, the expenditures might go up even during the idle period. But we will discuss that a bit later.

Practically all the components for the calculation model are known to us. We need only to define the cost per unit. I mentioned before, that in the middle of the seventies in the USA W_{DPW} = \$5 US/man-h. In 2010 with consideration of inflation it could be \$20.2 US/man-h and even \$28 US/man-h. [18]. In the USSR by the end of the eighties it was close to \$0.8 US/man-h. In Ukraine, for instance, in 2005 it could be equal to \$1.2 US/man-h. By 2011 this indicator rose to \$3.77 US/man-h.

Let us try to do calculations for several versions. For instance, let us assume a cost per unit for direct production workers, which is equal in Ukraine to \$1.2 US/man-h, with further growth in compliance with the data from the State Committee for Statistics on average by 13% between 2012 and 2020. And for an average European enterprise we assume a cost per unit equal in 2005 to \$8 US/man-h with further annual growth by 9% on average.

Let us preset the following initial data for calculation as of 2005: m_{com} = 280 kg, N_0 = 100 h. p., price per 1 kg of composite materials \$21 US/kg, engine unit price is \$189 US/h.p., price of airborne flight navigation instrument is \$6000 US. We will assume growth of PIP prices equal to

20%/year (engine – according to Fig 7: P_e = 76906 (2020–1995)+116.72), materials – 6%/year. The other initial parameters and their dynamics are preset above. These indicators are relatively moderate, and one can make sure of this, if we compare the costs of 2005 and 2020.

Table 1

Expenditures for production of LSA at K_{be} = 2 (200%)

Expenditures	2005	2020
Materials	5877	14085
Engine	18900	32100
Avionics	6000	92442
Business expenditures (Ukraine)	9139	8777
Business expenditures (Europe)	60925	33303
Prime cost (Ukraine)	39916	147405
Prime cost (Europe)	91702	171930

I should remind you, that for the time being, we speak about prime cost, but not the LSA price. And if we use the old method of price calculation, then at profitability of 10% the price of the aircraft manufactured in Ukraine, had to be in 2005 equal to $43,908 US, and in Europe – $100873 US, which is equivalent of 83380 Euro, and as such it represents a realistic indicator for that time. But if we assume for the same example for 2005 a cost per unit not $8 US/man-h, but, let us say, $12 US/man-h, then the price for an LSA in that year in Europe had to be equal to $134,381 US – a cost much too high even in Europe. But now we are interested not so much in figures, but in tendencies. Proceeding from Table 1 and Fig.11, it appears, that at the preset rate of price increase for materials, integral parts, as well as wages, inevitable overheads (200%) and reduced by a 20% labor-output ratio, and at the anticipated number of constructed aircraft, LSA prices by 2020 could reach $147,000–

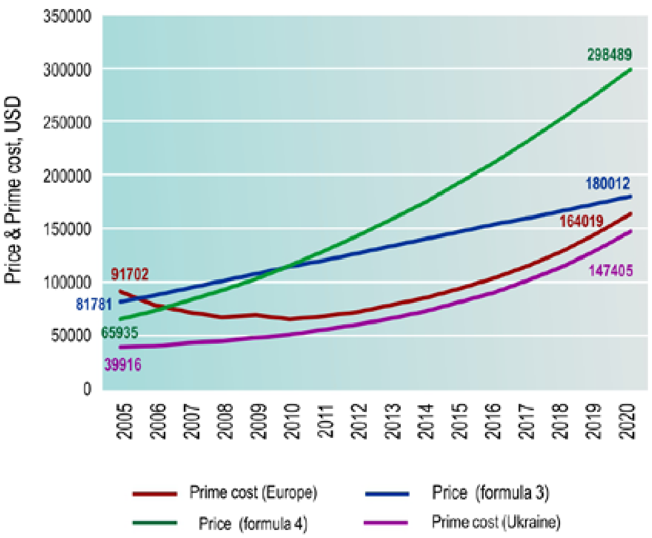

Fig. 11. Variation of price and prime cost of LSA

$189,000 US. This forecast is closer to data of Fig.4 as compared with Fig. 5, but on Fig. 11 the approximation of Fig. 5 is also indicated in order to point out the non-linear character of price and prime cost change. It is quite probable, that, if the engine unit price in 2020 is equal to $309 US/h.p., and we accept higher prices for flight and navigation equipment, by 2020 basic cost would be much closer to that forecast of Fig. 5. That is why you should not blame me, that one can be mislead by presumable excess profits, which the curves on Fig. 11 promise. We are not evaluating a business plan, but investigating tendencies. Moreover, our analysis of price forecast reality is not finished yet.

Let us see which way idle periods can influence the aircraft basic cost (See Formula 9). In our model in 2008 and 2009 the enterprise had to produce 24 and 48 LSA, respectively. As it is known for those years, due to the global economic crisis, sales of light piston-engined aircraft dropped to 50%. Let us imagine, that at our enterprise half the number of aircraft were constructed and marketed. As a result the average labor-output ratio per one LSA in 2008 became not 1544 man-h, but 1647 man-h, and in 2009 – 1397 man-h instead of 1295 man-h. It means that in 2008 demand for direct production workers had to be reduced compared to a full time employment year from 22 down to 12 people, and in 2009 – from 37 people down to 20. As compared with 2007, when the staff requirement was only 14 direct production workers, two workers were fired.

Let us assume that idle time of each of the remaining direct production workers, resulting from under-loading, annually reached in 2008 – 800 h, in 2009 – 500 h, and cost per unit during idle periods constituted only 75% of the basic salary, uncompensated for loss of work. Under such conditions wage costs and business expenditures during idle periods in 2008 constituted $50,000 US. In 2009 for assembly of 24 LSA direct production workers staff had to be increased up to 20 people. That is why, in spite of reduced idle periods, the losses constituted about $84,000 US. As a result, in 2008 basic cost turned to be equal to $68,198 US (instead of $62,062 US, the increase constituted nearly 10%), in 2009 – $69,264 US (instead of $61,986 US, the increase is nearly 12%). That effect can be seen as the small “bulb” on the diagram Fig.11 in 2008–2009. But under-delivery of 36 aircraft affected the whole further program, since the rate of reduction of labor-output ratio slowed down. Along with that, in order to produce and market 60 aircraft after the crisis, the enterprise would have to increase direct production workers staff in 2010 up to 40 people (Fig. 12.). There is no such thing as free lunch!

European enterprise suffered relatively minor losses during the idle period because in the estimates the overheads were adapted equal to 200% within the whole production period.

And let us imagine, that production of our two-seater aircraft is launched at some Ukrainian aviation plant, though with linear decrease of the overheads from 1000% in 2005 down to 300% 2020 (Fig.13).

Fig. 12. Change of direct production workers staff

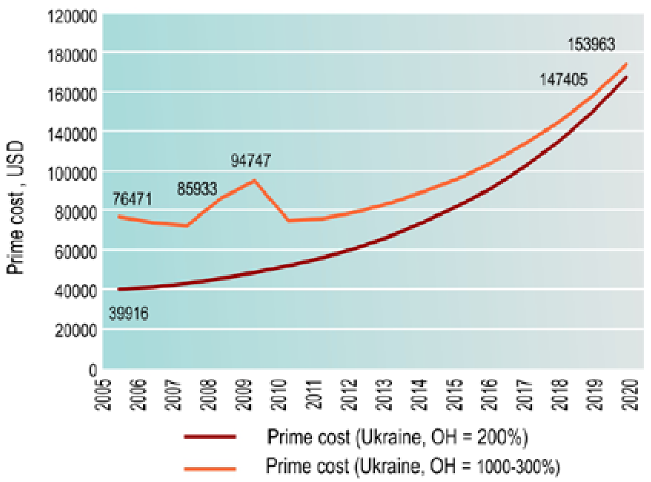

Fig. 13. Prime cost at decrease of the overheads from 1000% down to 300%

In this case, at the same wages, as at small Ukrainian enterprises, and the same prices for materials and integral parts, the basic cost of LSA in 2005 would have been not $39,916 US, but higher by 92% – $76,471 US. Along with that, during a crisis period, under the same parameters of production recession and idling in 2008, the basic cost would have grown by 88% from $45695 US up to $85,933 US, and in 2009 – by 95%, from $48,424 US up to $94,747 US.

I did not even consider the option with permanent high overheads, since from the initial years the production would have generated losses. But even at lower overheads, the losses due to idle periods and sales drop are much higher at such enterprises.

From here we can draw a very strict conclusion: it is impossible to manufacture ultralight aircraft, LSA and even light aircraft at aviation construction plants, which inherited gigantic overheads from the Soviet times, where per one direct production worker there exist five and even more employees of other categories. Figuratively speaking, the saying "one beats the bush and seven others catch the bird" quite vividly illustrates the essence of the problem.

Those, who studied economics can confirm that in all textbooks the breakeven point is found at the intersection of the lines of incomes and expenditures, which happen to be intersect only at invariable prices and prime cost, and linearly increasing volumes of production and sales. In reality not only in the aircraft building industry but also in "baker's" economics there are no straight lines, like in Lobachevski's geometry. Linear correlations are a special case, typical for a Soviet economy, when invariable prices were artificially preserved for years.

But nonlinear nature is not the only difference between the aircraft building and "baker's" economics.

Which way are the aircraft prices forecast to go?

If we carefully analyze the calculations, it will turn out that the non-linear nature of basic cost and prices of the aircraft both in GA and in big aviation are determined by the permanent increase of labor cost and the price of materials and integral parts. Moreover, one of the reasons of price increase for materials and integral parts, along with price increase for energy resources, is the same labor cost. So, both prime cost and prices "bend up" due to permanent increase of the wages, which outrun the rate of inflation. It is a World tendency. It is just the reason why in aviation industry of the Western countries it is a long-time practice to use formulas of aircraft price correction depending on increase of its basic factors: labor cost and direct tangible costs.

For example, Airbus and its dealers use correlation 10:

$$P_n = (P_b + F) \cdot [(0{,}67 \cdot (ECI_n / ECI_b)) + (0{,}33 \cdot (IC_n / IC_b))], \qquad (10)$$

where P_n – current price of the aircraft, calculated for the moment of the aircraft delivery date;

P_b – the aircraft basic price for averaged economic conditions at the moment of contract signing;

F = (0.005 x N x P_b), where N = calendar year of the aircraft delivery, minus year of contract signing;

ECI_n – arithmetical mean value of labor remuneration index ECI for the current year;

ECI_b – index ECI at the moment of contract signing;

IC_n – arithmetical mean value of tangible costs index IC for the current year;

IC_b – index IC at the moment of contract signing.

Labor remuneration index (Employment Cost Index) – «Index of expenditures for labor remuneration of the employees in the industry», hereinafter referred to as ECI – is calculated on the basis of tables entitled "Average wages according to types of industrial activity", which are usually published by state bodies for statistics (for example, State Committee for Statistics of Ukraine, or Bureau of Labor Statistics of Department (Ministry) of Labor of the USA).

Tangible cost index (Producer Price Index), hereinafter referred to as IC, is calculated on the basis of the tables, entitled "Price indexes of industrial product manufacturers", and published annually by the state bodies for statistics.

Correlations similar to (10) are applied also in other companies, with the only difference that in some formulas components are introduced which make it possible to keep some portion of the price invariable, change correlation of price increase share due to variation of labor cost (in formula (10) it is 0.67) and tangible cost value (0.33 in the same formula). The share of price linear growth also changes, which in formula (10) is determined by additive F. But a comparison of formulas for aircraft price forecasting is a subject for a separate article. For us the most important thing is that the correlations similar to (10), in principle, could be applied with respect to any type of aviation materiel, since they make it possible to evaluate change of the basic price due to variation of labor remuneration indexes and tangible costs, which are roughly the same for a particular industry in the country.

For example, if in 2000 the price for LSA was equal to $34,265 US, then after one year in Ukraine it should have carried the price of $42,917 US, in 2006 its price in accordance with Fig. 14–15 in Ukraine had to be nearly three times higher. Comparison of growth of labor remuneration and tangible cost indexes shows that in Ukraine, for instance, the prices for aviation products should grow more dynamically (Fig. 14–15) than in the USA. However, in reality everything is happening quite differently. It means that formula (10) for the time being reflects the real situation inadequately. Maybe linear component A and linear component F for LSA should be different, or maybe, the correlation of price increase due to labor and materials costs is not 0.67:0.33, but some different value. In any case, understanding the essence of what is happening in the industry on the basis of more deeper research it is possible to draw some useful correlations.

turn out to be unjustifiably expensive. And it is a poor consolation that by that time the income of potential buyers will also grow as a result of inflation. Aviation assembly plants can not influence their prices at all, since 83% cost will be formed by suppliers of materials (up to 8%) and PIP (up to 75%). Aviation building plants in the CIS have been suffering through such a situation for nearly two decades. Unfortunately we are familiar with the result.

Let us summarize. Today the principal distinguishing feature of aircraft manufacturing, to which in this case I attribute also aviation assembly plants, and integral parts suppliers, is use of expensive highly skilled labor, and relatively small lots of finished products (compared to the car manufacturing industry). On one hand it explains why inflation does not fully determine price increases – the wages of skilled workers grow, surpassing inflation indexes. On the other hand, small production volumes hamper the process of transferring to less skilled and less expensive staff. Only with massive production can the expenditures for expensive robot-aided cells are reimbursed. In production of commercial aircraft (transportation a/c and liners), where big capitalis available, and the production is supported by the governments, the process of unmanned technologies introduction develops pretty sweepingly. In production of superlight and light aircraft to apply such technologies is not feasible, and to be more precise it is impossible for the time being.

So, what springs out of all these things? If nothing changes, then after about eight years, or maybe earlier, the LSA market might wrap up. To buy expensive aircraft will be possible for a few fans from among very rich people. At this, two-seater aircraft will become for them like exclusive handmade sport cars. Such a scenario is not likely to satisfy most of the manufacturers, since in the event of a

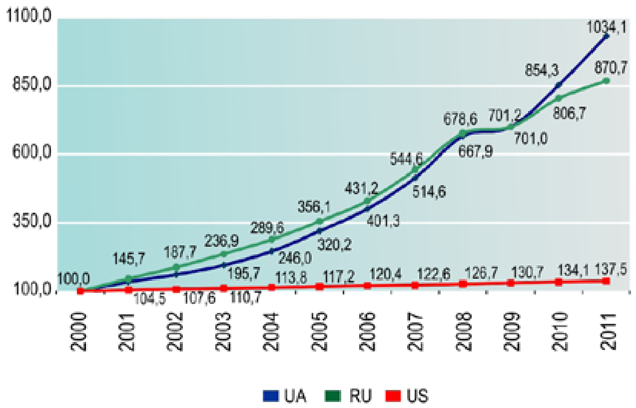

Fig.14 Comparison of variation of indexes for labor remuneration in Ukraine and the USA in the period 2000–2006

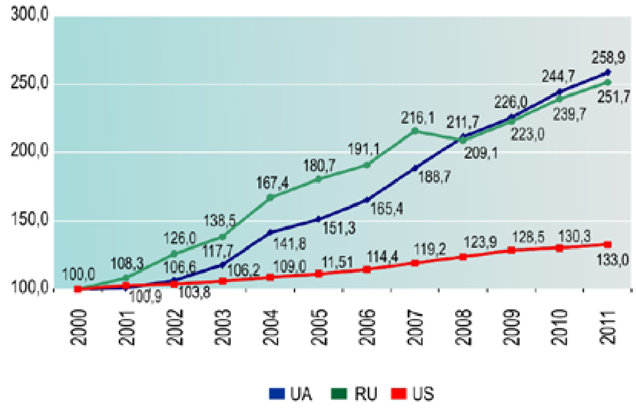

Fig.15 Comparison of variation of tangible costs index in Ukraine and the USA in the period 2000–2006

En avant to "Matrix"!

Notwithstanding that, for the time being no universal formula for LSA price forecasting is found, the model for evaluation of future basic cost already seems to be quite adequate. If we analyze the forecast structure of the LSA basic cost model 2020 (Fig.16), then even in the example with small fixed overheads, after eight years the LSA will

market collapse, most of the companies will go bankrupt.

How to avoid such an end? One of the versions is the appearance in the market of cheap engines and flight display units which will suit pilots and owners with respect to a price-quality indicator. But cheap PIP will not appear per se. A possible way out could be the use of the same integral parts in ultralight aviation as in car manufacturing. Such a suggestion may today seem pretty unprofessional from the point of view of those who are involved in certification of the aviation equipment, but there is nothing extraordinary in it. It has been a long time now since car engines are being installed on ultralight aircraft, and as the configuration of a modern car becomes closer and closer to ultralight aircraft in reliability and functionality the conjuncture may be inevitable. Presumably it is possible from a technical point of view to develop instrumentation which, having the same basic elements, could be reprogrammed and used either in the aircraft, or in the car. In this event, they would not cost so much as a modern glass cockpit.

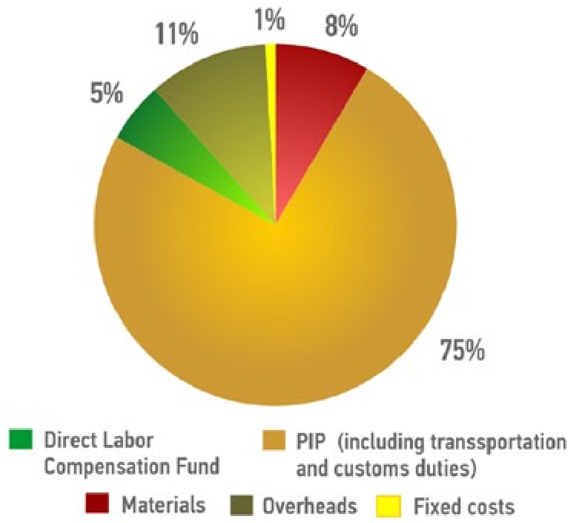

Fig. 16. LSA prime cost structure in 2020

Certainly another scenario is possible when one single manufacturer will produce not 60–300 aircraft annually, but several thousand. Then, both the integral parts and the aircraft will be cheaper. Many of you may even venture a guess where it will, presumably, happen [20]. The consequence will also be a reduction in the number of LSA manufacturers.

Robotic production of LSA, or at least sub-assemblies, and materials for them, seems fantastic today. It is hard to believe that such things may happen in the future, but as a distant prospect it is possible (or maybe I watched “Matrix” to much?). Moreover, it is clearly necessary to find a way out of the need for costly highly-skilled labor. That need is already recognized in big aviation.

It appears that the only real way out at present is some kind of coordination of LSA manufacturers on the World level with the purpose to work out common approaches to the problem’s solution. For the time being not many people seem to have thought seriously about what the LSA industry is facing, but sooner or later the coordination will have to be started. Perhaps the time has come for the Light Aircraft Manufacturers Association (LAMA) to address this problem?

As a final note, I did not intend to tinge the article in nostalgic or ideological shades. But I can not go without political one. Let us recollect the energy crisis at the end of the seventies, the result of which was a price explosion for crude oil and nine times drop in light aircraft production in the USA.

That is why today I unwittingly begin to think which way the probable conflict in the Eastern oil-producing regions is threatening not only to the whole world, but also our pretty small GA World community.

I would not like to finish in the worrisome tune. After all, if man is aware of future threats, he should maneuver to avoid them. We should give thought as to how to do it and to define workable scenarios more precisely. And then we may be able to catch the elusive happiness, otherwise we will have to drive antediluvian carts.

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NON-EUCLIDIAN ECONOMICS