INTERVIEW WITH DR. JAN ZIGMUND

4th "Rapier Summit 2007" took place in Brno Medlánky at the end of May. Photoreport from this event can be found [here]. During the meeting an interesting discussion took place between modellers and Rapier motor maker Jan Zigmund. As the questions asked might be interesting for MinimaketyCZ server readers I asked Dr. Zigmund by email, if he would give us an "email interview". He agreed and here below you have the chance to see his answers.

Dr. Jan Zigmund

On the last Sunday of May modellers of small scale models powered by Rapier motors met on at theRapier Summit in Brno Medlánky. You attended the meeting, what models caught your attention?

Dr.Z: I liked Yak 25M (which we saw last year as well) with two dummy nacelles but single Rapier in the fuselage "tunnel", which made a great powered flight low over the grass. This year I was surprised by two-part model of Mig-15, which had the motor inside the fuselage in a compartment, which is supposed to work as a thrust amplifier (augmenter). Incoming air should be warmed up by the exhaust gasses, increasing its volume and therefore increase the thrust. Turbofans in "adult airplanes" work in a similar way.

Are you a modeller yourself? What categories are your favourite?

Dr.Z: I used to build models when I was a kid; I was fascinated by SYNJET motors (equivalent to JETEX or JET-X 50). I built semiscale profile models – I remember one flight when the motor ran perfectly and the model flew just like the real thing.
I was also built model rockets. During my studies at military high school in 1973 I attended the course for rocket modelers' instructors. As the motors came off the market in Seventies, I stopped building the models.

Can you tell us about the history of the creation of Rapier motors? What was the inspiration?

Dr.Z: I had three motives in creating Rapier motors.

The first motive was a visit to a model shop with my son in 1997. I thought I would buy some cheap kit, build the model, and my son would have a good time. My son wanted a radio controlled helicopter. But when we got to the amount of 25,000,- CZK (over 1,000 USD) for the kit, motor, RC equipment, and we were still not at an end, I gave up and promised my son that I would think of something myself.

To mitigate my son's disappointment I told him about my childhood memories when Synjet motors were available together with kits of planes made of balsa. I promised my son that I would try to make such motors. I made up my mind to develop a safe motor for recreational flying, with low thrust and a long period of burning that would propel the model airplane to a height of 20-30m from where the model would glide back to ground.

The second motive was the desire to achieve an "engineering success". Let me introduce myself a bit: I have degree in chemistry with a specialization in the theory and technology of explosives. In my professional practice, I further specialized in high power propellants (the modern general term for solid fuel, powder charges, gunpowder, smokeless powder, etc.). I wanted to develop some simple thing, finance it myself and sell it. And the simplest product in my field is a model rocket motor. At least so it seemed.

The third motive was to answer the question, "is it possible to make one million Czech crowns in Czech Republic legally?" Today, I know: it is, but it's not worth the effort!

For how long has Rapier company existed?

Dr.Z: The Rapier Company was established on September 9th, 1998, when the decision of the Trades Licencing Office in Pardubice, regarding permit trade no. 307 (Research, development and production of explosives), gained legal validity.

The goal of the company was to start the production of motors for model airplanes and rockets at a reasonable price. The previous Czechoslovakian producer of model rocket motors, ZVS Dubnica nad Váhom, had ended their production. There was therefore a gap in the model accessories market, as there were no products for general public that gave modelers the romance of flights of models powered by rocket motors.

The goal of the company was to resume the production of SYNJET or JETEX. Motors should have low thrust and long duration and should be suitable to propel airplanes, cars and boats. The Rapier Company designed and started the production of such motors, but the motors are, in contrast to previous types, moulded in paper tubes.

For those who do not remember Synjet motors, I'll briefly describe its design. The motor has a duralumin combustion chamber with a removable end cap. An asbestos washer and a propellant pellet is put into the chamber, and a fuse in a spiral shape is added. The chamber is sealed with another asbestos washer and the end cap is secured by a clevis made of spring steel. The assembled motor is put into a bracket attached to the model. With careful application, the models flew well.

Rapier motors are designed as a paper combustion chamber filled with a propellant mixture enclosed by a fixed jet nozzle on one side and a cap at the front. Rapier motors are therefore meant for single usage only, in contrast to Synjet motors. The possibility of repeated use is replaced by easier and safer manipulation. The motor is simply put into a tube attached to the airplane and discarded after the flight. It is not possible to recharge the motor as the paper combustion chamber becomes carbonized to almost the full wall thickness.

The propellant mixture is of oxychlorate [perchlorate] type. Its ingredients are chosen so that no hydrogen chloride [HCl] is produced. This is ensured by a high surplus of propellant over the oxidizer. At the same time, a low temperature of combustion is assured, with a high ignition temperature for the mixture.

How long was it from the first idea to the first usable unit?

Dr.Z: I had a minor accident on 4th December, 1997. My hamstring broke, and I could not walk and I had to stay home for three months. My wife was working, the kids were at school and I had an unimaginable three months of free time.

You would not believe how huge the amount of work a single person can do when he has a goal, does not have to communicate with anybody, and does not have to work in a team.

I was able to extend my [computer] program for the thermodynamic calculations of propellants with modules for the calculation of the inner ballistics of barrelled weapons and rockets, [with] solutions for the optimum bore, etc. And, apart from that, I started thinking seriously about model rocket motor production. I concluded that the Synjet type motors were ideal to start with. Rocket modeling was [then] still a bit alive, as I realized when reading model magazines, but seldom did any information about rocket models competition appear.

I had following idea: if I could mix a propellant composition with a very low oxygen balance, the reducing environment of relatively cold combustion products would not allow fire penetration of the combustion chamber that was to be made of paper.

I wanted to use a special glue for the propellant mixture, paper tube composition and jet production. This special glue – epoxy – has the consistency of a natural resin. It can be dissolved in acetone to a dilution that adheres strongly, but when the acetone dries out it has consistency of natural resin again. From technological point of view it is a great material. One just paints the parts with the dilution and wait for diluent to evaporate. You can put parts together with no rush, strongly compress them (e.g. between two metal sheets) and harden at a temperature of 105 °C in about 15 min, as this glue also melts. I first wanted to make airplane models this way as well. A balsa – paper sandwich made this way has great physical properties and can be produced in amateur conditions. The glue has a hardening time of about one month at normal temperature.

The glue in the motor will harden in course of time and the motor become very strong, while the epoxy-bonded paper tube has a great heat resistance. So all parts of motors and models would be cemented together by a single glue. Fantastic! Later on I discovered that the propellant burning temperature is so low that paper tubes available on the market are adequate. Those with a wall thickness of about 1.3mm can withstand over 20 sec. of propellant burning. This greatly reduced the production cost, as we did not have to make the tubes, but could buy them for about 0.30 CZK per item. Apart from that, it is better if the [motor] tube does [come to bits] in water, so that a defective motor can be safely discarded. Epoxy tubes will never come to bits. Paper tubes eliminate the high cost of metal motors of the Jetex and Synjet type. Propellant pellets need to be moulded anyway, but the expensive technology of drawing or turning of duralumin motor chambers, jets, washers etc. is omitted. A metal motor would cost hundreds of CZK today. In England, a set of a motor with propellant and accessories costs about 20 GBP.

Paper tubes are adequate for commercial motors for both airplanes and rockets. The tubes are of stable quality and a reasonable price. Motors made of these can be considered a successful product, foreign customers prefer the motors over the American ones. In fact, when you look at the launch point from a longer distance during [rocket] competitions, it appears that the rocket parachutes are put into a single place in the sky. Here I have to mention that I use very high quality materials produced by Explosia a.s. Company.

When I started producing motors I thought that I could save money using cheap out-dated black powder. After complaints I was cured, and since then I buy only powder with guaranteed quality, even if it is more expensive than out-dated ones.

However, the paper tubes are not adequate for precise high power motors for the national team. These motors are rolled manually and hardened with a modern spreadable glue. One has to consider that the combustion chamber wall thickness for motors class A and B (2.5 and 5Ns) is only 1 mm thick, while it must withstand the heat of propellant burning for about five seconds. Motors of class E (40 Ns) have wall thickness of 2 mm; burning time is 10 - 30 seconds. The pressure the tube must withstand is about 8Mpa. Manual rolling of the tubes is the essential limiting factor for top class model rocket motor production. At the moment I'm working on the design of a roller with higher productivity.

Rapier motors are unique worldwide. What do you think explains their success?

Dr.Z: Whilst thinking about jet motor design I considered two versions of combustion chamber design:
1. Metallic, commonly used in Synjet, Jetex and Jet-X motors. I had no equipment and no experience of production for such type. I know the technology of shell casing production. You need machines, metal sheets that can be drawn to the cup shape, and you have to know how to do the stuff. Further technology is required for spring shaping, nozzle cutting and brackets for motor mounts. Also asbestos washers are forbidden now.
2. Paper, as in motors for model rockets. I was not sure whether the tube could withstand the heat of burning, as, compared to rocket motors, longer times were required. I wanted to achieve a burning time of 5-10 sec. I proposed a propulsion mixture based on AP [ammonium perchlorate] and zinc As the combustion exhaust should not contain hydrochloric acid, a chemical composition was selected to achieve a very low oxygen balance and therefore a low combustion temperatures. As one can see from thermodynamic calculations, a proportion of the zinc sublimes and removes heat from the motor, which, during the first attempts, surprisingly worked for over 10 seconds.

Low thrust long duration rocket motors with ceramic (clay) nozzles for model airplanes are considered as invention. I'm the only author of this idea.

Do you remember the first Rapier powered model? Don't you have its photograph?

Dr.Z: The first model was a bit funny. After a 30 year break in modeling, I off course had lost the skills. I made the first model at the end of March, 1998. It was an L-159 made of three balsa sheets. The nose weight was made of an M3 nut and bolt, and instead of a container[for the motor] it had a bracket made of wires shaped like question marks. The camouflage was made of irregular areas of red, green and black, as I made it by alcohol markers I found somewhere. We mixed the propellant, my friend stole some spools from his wife and we packed 5 motors for first flights. We went to the meadow over the village, prepared model, lit up the

motor and hand launched. The motor fell off and burned up in the grass.
Second – the same.
Third – the same.
So I took some pliers, bent the wire question marks a bit more, lit the motor and threw the model in the air. The L-159 model hung around, did not really fly, and landed on the ground. Afterwards I put on trim tabs made of adhesive tape on the rudder, stabilizer and wing tips, test glided it first, lit up the motor and launched. The model made three beautiful loops, gaining height of about 15m, where it straightened into a glide and finally made a great landing. And we stood there with our mouths open: WooooooooooW! So the first flight test was successful and the propellant used that day is still used now.

To control the power output of the motor the ratio between retardant and catalyst is changed. [In this] way I can produce powerful HP motors (high power), or motors with a long operational time LT (long time / low thrust).

I believe the first flight day was March 25th, 1998. We had a blue sky, sunny day and it was pretty warm for March. A video was shot, which is currently held by my former associate, who, in contradiction with our deal, refuses to lend it to me.

L1 a L2

What is the actual range of motors regarding size and thrust?

Dr.Z: At the moment we are producing motors labeled L-1, L-2, L2-HP, L2-LT and L3. L-1 motors have nominal thrust of 60 mN; L-2 motors about 120, 130, sometimes reaching 140mN; L-2HP motors in range of 200-220mN; L-2LT motors, 80-90mN; L-3 motors, 300mN or more. Further technical details, such as size and weight, are listed on the company website at www.rapier.cz

Can you tell our readers more about actual production of the motors?

Dr.Z: Motor production is divided into three steps.

1. Propellent preparation – granulation:
   the powder components of the propellant (AP, Zn, burn rate retardant + others) are carefully mixed and then wetted with diluted binder. The concentration of binder in the diluent must be such that during the propellant mixing the highest possible amount of powder components are changed to granules. The total yield is between 60 - 70% when correct ratios are used. Wet material is carefully put over a 1.6mm sieve, open to the air, and as it gradually dries out, all the material finally goes through the sieve. Fine fractions of material are separated with a fine sieve and returned to the mixer, so finally there are no fine fractions of propellant. The technique is therefore wasteless. Several batches of propellant are homogenized after drying and are used for the production of one series of motors. The difficulty of this operation is in the necessity to choose a concentration of binder that enables correct granulation and the proper propellant burning speed.
2. Clay used for nozzle is granulated the similar way
   Here sodium silicate dissolved water is usually the binder; sometimes a solution of plastic in an organic solvent is used. With the proper concentration of binder most of granulated material is up to 5 mm in size. After pre-drying, the granulated clay is crushed between cylinders to achieve a size below 2 mm and then sieved to fractions of 1.6, 1.4, 1.2, 1.0 and 0.8mm. Fine fractions are returned to material mixing step. This technique is also wasteless. A few weeks ago I managed to build continuous production line for

granulated clay crushing, which made one difficult technological operation much easier. I want to add a continuous sieving machine into the line in the near future. Granulated clay is dried first in the air, then in a drum drier heated by warm air. When dried and cooled I add soap, which makes the press moulding easier.

3. Motor moulding

The paper tube which forms the combustion chamber of the motor is put into a steel die. The plug has a bottom plate with a spike to shape the nozzle. A sliding feeder measures out the granulated clay which is press moulded by the pressing mandrel with a shaped cone [to produce] the nozzle taper. Another sliding feeder measures and moulds three loads of propellant. Finally the motor is closed with a cap made of granulated clay measured by a third sliding feeder. Forming pressures are about 100MPa. The bottom plate with the spike is removed from the pressing tool and the motor is removed from the plug by pressing the mandrel. The motor nozzle is cleared with a drill. The burning time and thrust of the motors is measured for various nozzle diameters. A whole batch of motors is then produced using the drill with which the required power parameters were obtained. Motors for the trade network are packed into green or red boxes together with fuses and operating instructions. The box is secured with sticker, the date is stamped and burning time, thrust and total impulse is labeled.

Are you currently capable of covering the demands?

Dr.Z: At the moment I'm covering about 1/2 - 1/3 of the demand. This year I plan to build at least the hardware for a semi-automatic machine for production of the most popular motors. I have problems with the orders "one box from each type". One has to consider that the production is based on the orders, and large orders are made preferentially. So it is difficult to get the tools ready, make one box of different type of motor and then return to the first order. Sometimes the modeller is lucky and gets the motors in a couple of days when he rides on the 'coat tails' of a bigger order; on the other hand, he may have to wait for several weeks. I hope that modellers will understand the situation: small orders are always a problem in serial production.

Do you know in how many countries we can meet Rapier powered miniscales?

Dr.Z: Apart from Czech Republic, Slovak Republic and Poland, I have many fans in Great Britain, USA, Germany and Italy. Sometimes other states: Sweden, France, Slovenia. The most distant country I got an order from was Australia. Sometimes people from European countries stop by in my home and buy the motors directly.

Last year an Internet discussion started regarding the fire penetration of L2 motor tubes. There were quite a number of complaints and photographs of burned models in jetex.org and the thread entitled "DEFECTIVE MOTORS burned Up Models" is still very active and full of speculations as to what happened and why. Was it a problem with motor design, tubes or propellant production technology, storage, or is there another theory?
Are the problems solved?

Dr.Z: The problems with fire penetration of the combustion chamber were probably caused by the extremely hot and dry weather in 2006. Paper tubes are stored in attics in a dry place. The natural moisture of the paper used for the tubes production is about 8%. Tube drying reduces their diameter, tubes put into the pressing machines are a loose fit and are falling off the machine. During moulding (100MPa) the cellulose threads of paper tubes expand and the paper becomes thinner. This is hard to detect as the motors have the same diameter. But as I found later, the number of fire penetrations increased from a negligible value to about 50%. I can't think of any other explanation. Tubes are the same, propellant is the same, and this year (so far) I have no complaints reported. Only slight browning appears on the tubes. At the moment I store the tubes in a different environment with smaller variations of temperature and humidity.

I would like to ask the modellers hit by the "catastrophes" of their models [burning up] to show clemency and understanding. I'm ready to replace the defective motors. I would also like to recommend not to put the motors into PE [polyethylene plastic] bags under a car back window. The heat leads to the evaporation of moisture from the motor tubes and its condensation in the bag.

The next question is about the motor boxes, namely the labeling. There is no batch number or production date on the box so it is very hard to keep them in order when one has high number of boxes at home. Do you plan to put at least the production date onto the box?

Dr.Z: I, and other producers, are required by the Czech board for testing weapons and ammunition to label every product, or if not possible, then every smallest commercial package, with the batch number, production date and other technical data characterizing the product. I'm trying to keep to this requirement; motors in the shops have always at least the thrust data printed.

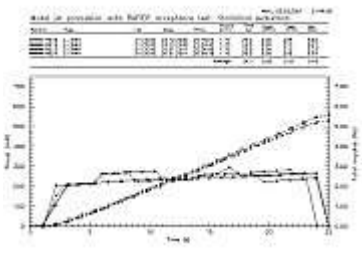
If I produce several thrust categories from one type of the motor, the HP (high power) motors will be labeled with red cap, red nozzle or red ink on the nozzle. The LT motors (long time - low thrust) will be labeled the same way but with green color. ST (standard) motors will have no marks.

I usually pack the motors in a hurry and even if the stamping is the last and the simplest operation, sometimes I just don't have the time. I will try to correct this and every box will be labeled with the production date.

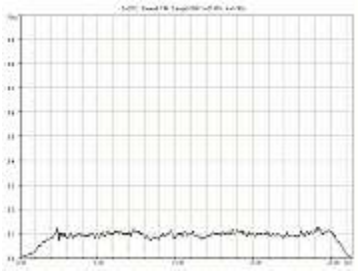
What do you think of the thrust test of L1 motors which Ruja made and which is available here on Minimakety.CZ server? Was it useful for you?

Dr.Z: I will mention a few notes from the past:
I started to measure the motors using mechanical post scales. I attached the motor holder to the upper plate where the letters are normally put. Let's say that L1 motor including the holder weighs 12g. After the ignition the motor starts to create thrust, let's say again 60mN (6g), so the indicator shows 18g. As the propellant is burned up the indicator shows less and less and finally when the burning stops it jumps [drops] from 15g to 9g. I dictated the values the indicator was showing into a dictaphone for, e.g., the 20 seconds of motor operation I recorded 20 values of thrust this way. The weight of empty motor with the holder is subtracted from each point of the curve (the final value measured – 9g). This way the right hand side of the curve is normalised to zero value in y axis. As the propellant consumption is constant during the burning I multiply each point of the curve by *3/20 x n*, that is the weight of the propellant in motor divided by burning time and multiplied by the number of points. This will normalise the graph so its initial y [axis]coordinate also equals to zero. This way of thrust measuring is very simple and cheap. And is sufficiently precise to differentiate between motors with a nozzle diameter difference of 0.1mm.

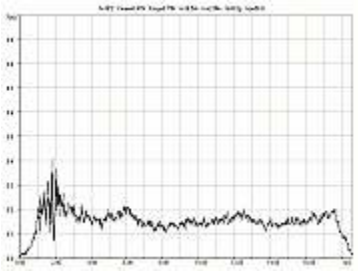
Further measurements were performed with the tensometric measuring device REDALS built by my friends, rocket modelers.



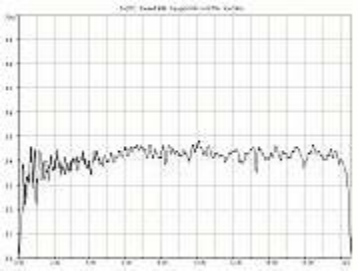
Measuring L2 using post scales



Tensometric measurement of L2



Tensometric measurement of L2-HP



Tensometric measurement of L3

Regarding Ruja's measurement published on this server, we have to consider that thrust of L 1 motors is 50 - 60mN ie. 5 - 6g, which is a small value. The motors work at the low pressure, roughly 2 bar (probably subsonic flow), so the propellants are not burning regularly. This causes the thrust fluctuations. But don't panic. The drag force depends on the square of velocity, from the balance of forces in steady flight we can see that the velocity changes with the square root of thrust. If the thrust changes by e.g. 25%, the flight speed of the model changes 5%. As one can observe, the models are flying pretty consistently. What concerns me more is the increase of the thrust at the end of burning, which is caused by the clogging of nozzle by combustion products. As the weight of propellant decreases the model has the tendency to make a loop at

the end of the flight. This problem can be solved by using slower propellant in the final part of motor moulding.

The lower the thrust of motor, the more difficult it is to make two batches of motors with the same thrust. The nozzles are accurate to within 0.1mm. The thrust depends on the nozzle diameter and can vary in range of 1 - 2g.

It really can be a problem to ignite a motor with a nozzle of about 1.5 mm. I advise modelers to clean the nozzle prior to starting with a drill or watchmaker's screwdriver. Sometimes it happens that the clay gets into nozzle where it works as a blockage and makes the motor more difficult to start. I cannot write this recommendation to user's instructions as the authorities would not like that. But the Apogee company recommends that on their web pages. I would only add that safety glasses would be needed.

I have heard that you are still waiting with [to produce] your own miniscale model, but the idea is slowly taking shape. Is the decision coming? What type of airplane would be your favourite?

Dr.Z. I will probably try an L-159. But I have to note that motor production is eating up all my time and to start new technology might be difficult. Any problem solved by a modeler in a minute can take too long with serial production. For example, if the model has problems flying, it usually means to bend something or sand something, but in serial production that means to correct the moulds. Not much free time remains.

If my numbers are right the next year you will have 10 years from the company start. Will there be a celebration?

Dr.Z. You are right, next year we will have 10th anniversary. During the Rapier Company's existence I have encountered both envy and friendly help. After I had to leave my own Company thanks to the "kind" efforts of my former associate, I went to see my friend Zdeněk, who lent me a pressing machine and let me use his workshop for the production of the first series of motors for tests and certification. I have to say that Zdeněk was very patient as I was visiting almost daily and restricting him whilst he had enough of his own troubles. This way I want to thank him to heaven. When we were composing the contract for the lease told me, "Honza, you have this for two years only, as I will die in two years". And he was not shooting a line. In two years and a few days he died of larynx cancer.

The second person who helped me and I would like to thank is the uncle of my wife. He offered me 20.000 CZK, I had ten thousand of my own, so I put first 30.000 CZK to start the production.

The tenth anniversary really reserves a little celebration and an idea is emerging. It will probably happen during "Rapier Summit 2008", but I will not reveal anything else at the moment.

Thank you for this email interview and for MinimaketyCZ server. We wish you many happy customers in the tenth year of Rapier company.

Interview was prepared by ISim & Ruja. We would like to thank Dr. Roger J. Simmonds and Steve Bage for careful reading and editing the English version of this interview.

Editorial note: This interview was made using certain "iterative" process and during this process we received further interesting materials from Mr. Zigmund. We well definitely return to Rapier motors, its production, measuring and testing on the pages of this server.