The new Peter Madsen project

Published 2014-08-15

News

Welcome to the 2nd edition of *The new Peter Madsen project*.

A section about the Pilz guidance system is now available at page 12.

The description of the consumable catalyst bed at page 6 has been improved.

Thanks to Morten Rasmussen and Michael Eriksen for comments and assistance with proof reading.

The project

Peter Madsen announced[1] in june 2014 he was about to embark on a new exciting spaceflight project. He had just left the successful spaceflight project Copenhagen Suborbitals which he founded with Kristian von Bengtson in May 2008[31,32]. He decided it was time to head back to basics.

We need to *invent something new* he said[1],

> *space flight as small science. Like something that begins with two guys in a garage and ends with two guys in a garage — but with a manned spaceflight in between.*

He had seen how the fascination with advanced engineering gear diverted the efforts in Copenhagen Suborbitals away from simple solutions and towards complex solutions.

Peter admitted he was derailed by the inspiring beauty of early manned spaceflight like the american Mercury program[1].

> *I was unable to resist the temptation*

he said, and

> *Please forgive me. I am only a poor art-engineer. I love the aestetics of space flight and was lost in the trap of beauty.*

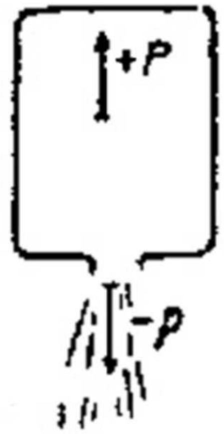


Fig. 1

Oberth 1929.

The new project was about a revolution. The revolution of manned spaceflight on a shoestring budget. The magic altitude of 100 km was not important anymore. The important target was getting airborne. He said[1]

> *I am not obsessed with the Karman line to begin with. A hop to 22 km with a rocket vehicle will be a supersonic psychopatic experience — a trip to 40 km pretty fancy, and a trip to 120 km the ultimate suborbital experience.*

In Copenhagen Suborbitals the productivity was about one sea launch per year. Peter said, *we need to get beyond one launch per year, and get something airborne with a considerably different launch rate.*

The idea is to focus on manned space flight instead of 100 km altitude. It is more important to get airborne than to get to a particular altitude[15] .

You need to do manned flight before you get to 100 km

he said. Because space begins at 100 km, we need to get used to the idea of *rocket flight* before we do *space flight*.

1. Peter Madsen: ”Her er rumplanen!” In english, ”Here is the spaceflight plan!” Published on `ing.dk` 2014-06-17 13:11.

15. Peter Madsen: ”Ild, røg og flammer, beslutningsunderstøtning for raket artillirister”. In english, ”Fire, smoke, and flames, decision support for rocket artillerists”. Published on `ing.dk` 2014-07-10 12:57.

31. Peter Madsen and Kristian von Bengtson: ”Katapultsæde-motor-afprøvning gik over al forventning!” In english, ”Ejection seat motor test successful beyond expectation!” Published on `ing.dk` 2011-07-31 21:55.

32. Thomas Djursing: ”Raket-Madsen forlader Copenhagen Suborbitals”. In english, ”Rocket Madsen leaves Copenhagen Suborbitals”. Published on `ing.dk` 2014-06-10 10:21.

Booster

The upper section to the right in the drawing is the 80 per cent H_2O_2 oxidizer tank. The solid fuel, probably polyurethane, is in the lower section to the left. The tail fins are detachable for ease of transportation. The nozzle will be made of pyrolytic carbon[22,24]. Booster drawing by Anders Klyver.

Peter Madsen proposed[1] a hybrid propellant

> *pressure fed vehicle using common nitrogen gas for pressurization of hydrogen peroxide. The concentration should be 80 per cent, which T-Stoff factory II delivers within one or 2 per cent.*

The *T-Stoff factory II* mentioned is a hydrogen peroxide purification facility Peter Madsen built[27] at the end of 2013.

Hypergolic ignition would be possible

> *with a "consumable catalyst bed" which might be open cell polyurethane foam dusted with* $KMnO_4$ *powder. We used that at my last test in Copenhagen Suborbitals.*

A catalyst bed will only be used if restart capability is required. In other words, Peter Madsen relies on thermal decomposition of H_2O_2 in the combustion chamber once catalytic ignition has occured.

Peter later added[39] that a catalyst bed could be valuable in case of combustion instability. *In case of instability in the hybrid engine the combustion chamber pressure and the injector pressure may be decoupled by means of a catalyst bed.*

Passive blow down pressurization will be used in the first *boiler plate version* of the booster. That means the oxidizer tank will contain up to 65 per cent liquid oxidizer and 35 per cent nitrogen pressurization gas[21].

This kind of pressurization system is the most simple system known. It is the easiest system to develop and implement.

The downside is that you cannot get a high mass ratio with this system.

However, the mass ratio is not critical in the first phase of the project where altitudes like *20 km to 40 km* will be considered a fine result[21] .

The nozzle will be made of pyrolytic carbon[21] like the HEAT-1X nozzle[22,24] . A piece with a mass of 96 kg was used. It was turned to the desired shape with the big Tyrannosaurus Rex turning lathe[28] .

The pyrolitic carbon erosion rate is[26] $0.6\ \frac{mm}{s}$.

Peter Madsen and his associates cast a 500 kg block of polymer[26] in 2011.

1. Peter Madsen: ”Her er rumplanen!” In english, ”Here is the spaceflight plan!” Published on `ing.dk` 2014-06-17 13:11.

21. Peter Madsen: ”Fare: teknikbasker... Hybridmotoren, set indefra”. In english, ”Danger: Techie knockout... The inside of the hybrid propellant engine”. Published on `ing.dk` 2014-07-14 13:50.

22. Peter Madsen: ”Hybridraketten / spåntagningsproblemet”. In english, ”The hybrid propellant engine / the turning chip problem”. Published on `ing.dk` 2011-04-24 09:27.

24. Peter Madsen: ”Opsendelse fra Nordsøen af HEAT måske allerede til sommer”. In english, ”Launch of HEAT from the North Sea possibly already this comming summer”. Published on `ing.dk` 2009-09-23 15:02.

27. Peter Madsen: ”God jul fra Peter Madsen!” In english, ”Merry Christmas from Peter Madsen!” Published on `ing.dk` 2013-12-24 15:08.

28. Peter Madsen: ”Tyranosaurus Rex brøler!” In english, ”Tyrannosaurus Rex roars!” Published on `ing.dk` 2011-09-15 00:53.

39. Peter Madsen: ”24. juli 2014 — døgnrapport fra et Rumlaboratorium”. In english, ”July 24, 2014 — daily report from a Space laboratory”. Published on `ing.dk` 2014-07-24 21:28.

Engine test

In april 2014, Peter Madsen and his associates performed 3 test burns[7,8] of a 1 kN hybrid propellant engine with a throat diameter[33] of 30 mm .

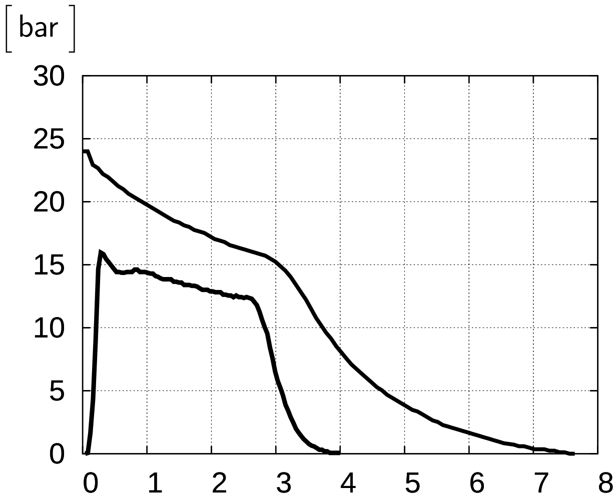
The tests indicated that a sea level ISP of more than 160 s was attainable.

The engine used medium density fiber board MDF as fuel and 80 per cent[7] H_2O_2 as oxidizer. MDF is a wood board product made of wood fibers.

During each burn the combustion chamber pressure was recorded as a function of time and the propellant consumption was recorded by using a weight before and after each burn.

With measurements of pressure, propellant consumption, throat diameter, and time, the team was able to compute the characteristic exhaust velocity as described in Sutton[12] page 64.

The results are tabulated below.



The upper line is the propellant feed pressure. The lower line is the combustion chamber pressure.

The propellant tank was filled 33 per cent[8] with oxidizer. The pressure drop over the injector was designed[8] to be 5 bar. Ignition occured[7] in 20 ms to 50 ms .

According to Peter Madsen[33] and Niels Foldager[7] the fuel grain had an outer diameter of 220 mm and had 7 ports each with a diameter of 40 mm .

	Test 1	Test 2	Test 3
consumed T-stoff	2,000 kg	2,000 kg	4,000 kg
consumed MDF fuel	0,411 kg	0,326 kg	0,762 kg
Medium chamber pressure	10,66 bar	9,69 bar	10,767 bar
Burntime	4 sek	4 sek	7,5 sek
O/F ratio	4,86	6,13	5,24
Characteristic velocity	1290 m/s	1250 m/s	1295 m/s
Estimated sea level ISP	167 sec	163 sec	168 sec
Estimated high altitude ISP	219 sec	212 sec	220 sec

The oxidizer flux[7] was $70\ \frac{kg}{s*m^2}$.

The regression rate was[7] $0.6\ \frac{mm}{s}$.

After a burn[21], the 7 ports of 40 mm diameter had increased to 65 mm and they were still fully cylindrical down the length of the grain.

7. Peter Madsen: ”Dejlig testdag i CS — mens vi bevæger os fra asken til ilden (HEAT 2X)”. In english, ”Nice testday in Copenhagen Suborbitals — while we move from bad to worse (HEAT 2X)”. Published on `ing.dk` 2014-04-21 22:58.

8. Peter Madsen: ”Hvad man virkelig kan lære af et eksperiment”. In english, ”What you can truly learn from an experiment”. Published on `ing.dk` 2014-04-22 18:30.

12. Sutton, George P, and Biblarz, Oscar: ”Rocket propulsion elements”, 7th edition, published by John Wiley and sons, inc, 2001.

21. Peter Madsen: ”Fare: teknikbasker... Hybridmotoren, set indefra”. In english, ”Danger: Techie knockout... The inside of the hybrid propellant engine”. Published on `ing.dk` 2014-07-14 13:50.

26. Peter Madsen: ”Alt er klart til weekendens dobbelttest ... men vi presser citronen!” In english, ”All clear for the double test this comming weekend — but we squeeze the lemon!” Published on `ing.dk` 2011-11-21 17:44.

33. Peter Madsen. Email 2014-07-23.

Launch site

No wonder Peter Madsen had a crush on our beautiful neighbor. This is Iceland.

Launch site

Peter Madsen came out of Copenhagen Suborbitals with substantial experience with sea launch operations[24]. He found sea launch was a complex logistic operation, so for this new project in 2014, Peter began by considering land launch.

But there is a catch. Denmark does not have any large, uninhabited areas suitable for rocket launch.

Peter looked around and soon had a crush on one of our beautiful neighbors.

Iceland.

He talked about this early in the project[1].

> *Blue Water Shipping takes 11 000 dollars to deliver 2 containers with 800 kg UN 2015 from my workshop in Copenhagen, Denmark, to Site A, Iceland, which is 250 km east of Reykjavik.*

It seems Peter recovered from this crush on Iceland in a few weeks. He settled on the idea of sea launch and decided to use a flip device[23].

Iceland is attractive for suborbital rocket flight, but public regulation usually makes land launch difficult. For scale, note the cars approximately in the center of the image.

9. Peter Madsen: ”Her er rumplanen!” In english, ”Here is the spaceflight plan!” Published on `ing.dk` 2014-06-17 13:11.

23. Peter Madsen: ”Sea launch flipper 2.0”. In english, ”Sea launch flipper 2.0”. Published on `ing.dk` 2014-07-02 23:53.

24. Peter Madsen: ”Opsendelse fra Nordsøen af HEAT måske allerede til sommer”. In english, ”Launch of HEAT from the North Sea possibly already this comming summer”. Published on `ing.dk` 2009-09-23 15:02.

Pilz guidance

In Copenhagen Suborbitals Peter Madsen participated in a project with[18] Flemming Nyboe, Steen Andersen, Niels Foldager, Søren Gregersen, Flemming Rasmussen[16], and others, on the implementation of an active guidance system in the test vehicle Sapphire.

The active guidance system worked as intended on the very first launch and the vehicle flew straight up into the sky at 12:42, June 23, 2013[19].

Peter Madsen praised the work[19] and the courage[17] of Flemming Nyboe, who developed the guidance software, but was not convinced active guidance was the right choice.

In the quest for the lowest possible level of complexity, Peter Madsen said active guidance had to be put aside. A simpler system was needed. Some kind of passive guidance system[25], he said.

> *Sounding rockets have been launched to more than 300 km altitude with more than 300 kg payload — without active guidance and without a high initial acceleration.*

Peter suggested the use of a unique guidance system invented by the german engineer Wolfgang Pilz.

16. Peter Madsen: ”Så mange gryder i kog!” In english, ”So many irons in the fire!” Published on `ing.dk` 2013-02-25 20:56.

17. Peter Madsen: ”Kuala Lumpur — en oplevelse!” In english, ”Kuala Lumpur — an experience!” Published on `ing.dk` 2013-10-05 16:28.

18. Peter Madsen: ”Nyt om Sapphire og Spectra”. In english, ”Latest news on Sapphire and Spectra”. Published on `ing.dk` 2012-09-02 10:18.

19. Peter Madsen: ”Efter Sapphire: Ingenting er helt som før”. In english, ”After Sapphire: Nothing is the same”. Published on `ing.dk` 2013-06-24 17:57.

25. Peter Madsen: ”Så skal det handle om teknik!” In english, ”Time for technical talk!” Published on `ing.dk` 2014-06-21 15:07.

The patent

Wolfgang Pilz took out a french patent[38] on his wire guidance system in 1950.

The patent was issued 3 years later on April 22, 1953 and was allocated patent number 1 035 553.

The patent consists of 2 pages. The first page contains the textual description of the invention. The second page contains 4 small drawings.

On the following pages is an english translation of the patent. The drawings are the original drawings from the patent.

The text

> *Demandé le 16 mai 1950,*
> *à 15 heures, à Paris*

means

> *Application received May 16, 1950,*
> *at 3 o'clock in the afternoon, in Paris*

38. Wolfgang Pilz: ”Dispositif destiné à assurer le démarrage où le lancement des engins autopropulsés”. In english, ”Method of ensuring a stable start or launch of rocket vehicles”. French patent number 1 035 553. Submitted 1950-05-16. Issued 1953-04-22.

RÉPUBLIQUE FRANÇAISE

MINISTÈRE
DE L'INDUSTRIE ET DE L'ÉNERGIE

SERVICE
de la PROPRIÉTÉ INDUSTRIELLE

BREVET D'INVENTION

Gr. 11. — Cl. 4. N° 1.035.553

Dispositif destiné à assurer le démarrage où le lancement des engins autopropulsés.

M. Wolfgang PILZ résidant en France (Eure).

Demandé le 16 mai 1950, à 15 heures, à Paris.

Patent certificate.

Method of ensuring a stable start or launch of rocket vehicles.

a. A method of ensuring a stable start or launch of rocket vehicles by forcing the axis of the vehicle, and therefore the direction of the thrust, to a given direction as a function of the altitude, until the speed is sufficient to allow aerodynamic stabilization of the vehicle by means of fixed tail fins or by a tail provided with actively controlled aerodynamic surfaces.

This method is characterized by the way the direction of the axis of the vehicle is determined by (at least) 3 taut lines fastened, at one end, on (at least) 3 points at the vehicle, and, at the other end, on (at least) 3 corresponding firm points at the ground.

The length of each line is in any altitude a function of the length of the other lines (see figure 1).

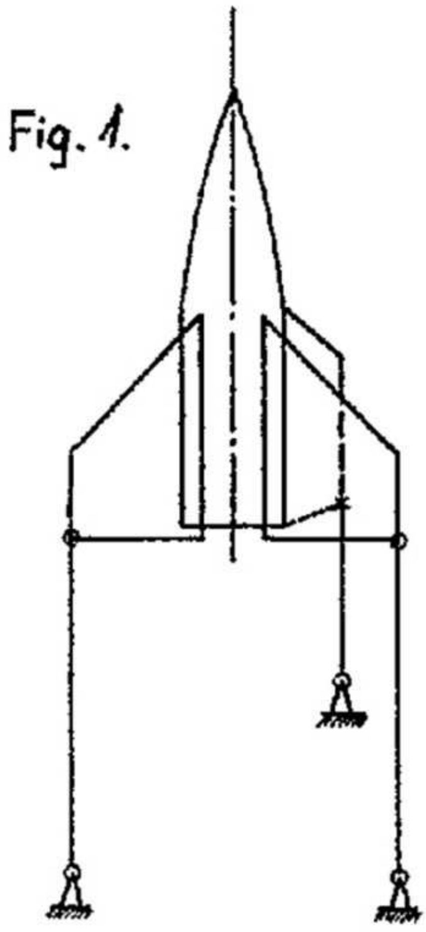


Figure 1.

b. A method to force in any altitude the vehicle on its trajectory guided by the length of all the lines of the guidance system, the length of the lines being related to each other by means of the unrolling of the lines from a single drum, or several drums, such that the rotation of each drum agrees with that of the others.

The tension of the lines of the guidance system is produced by braking of the drum (or of the group of drums), or by the inertia alone of the drum (or of the group of drums). The fixed points at the ground are implemented with pulleys that let out the lines of the guidance system (see figure 2).

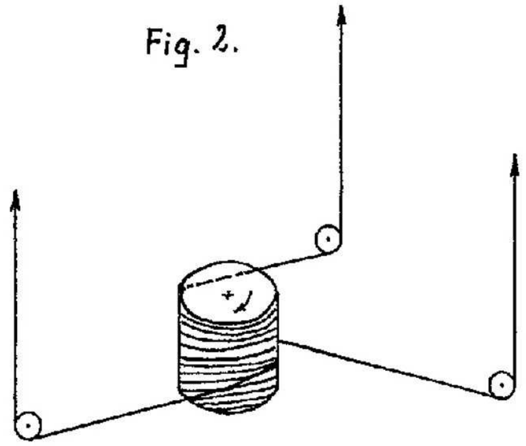


Figure 2.

c. A method based on the principle of paragraph a that works according to the method of paragraph b and allows you to select at any instant, before launch as well as when the vehicle finds itself on its guided trajectory, among a multitude of shapes of trajectories from an adjustable program.

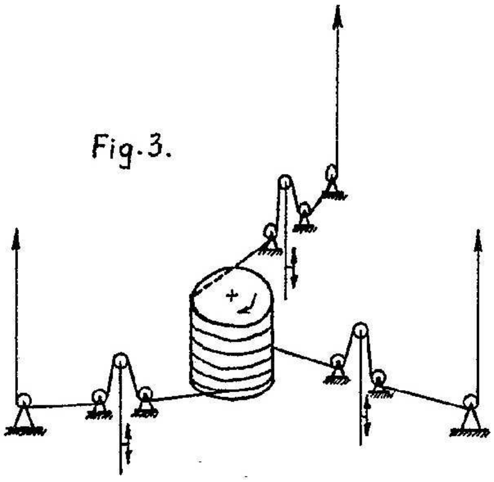


Figure 3.

The control is done

1. By means of manipulation of the length of the guidance lines during the unrollment (see figure 3);

2. By means of manipulation of the position of the points on the ground (pulleys for the unrollment of the lines) during the unrollment of the lines (see figure 4).

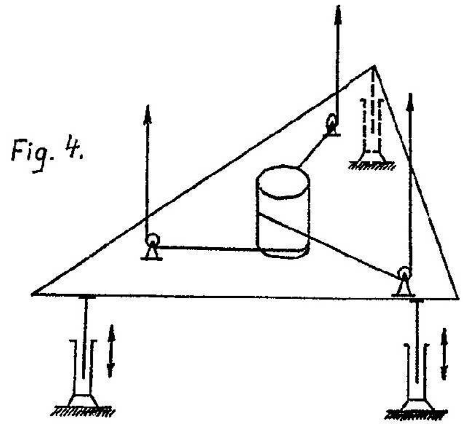


Figure 4.

WOLFGANG PILZ,
Vernon (Eure).

Comments

Patents are often composed in a rather convoluted language, possibly because lawyers are involved. Let us briefly go thru the text.

Point a, b, and c are the claims of the inventor. Each point begins with *Un dispositif*, or in english, ”A method”.

The first sentence in point a seems like a rather big mouthfull, and it is presumably only in a patent you might find an attempt to explain all of that in one sentence. Let us take a look at the elements of that sentence.

The first part seems clear.

Then we get to the part about *a given direction as a function of the altitude*. The french is *en fonction de l'altitude*, which is translated directly to *a function of*.

In practical terms, we know the invention was primarily used for keeping the direction of the thrust vertical, or at least at a constant angle. The word ”function” seems to imply that the direction might change in all kinds of strange ways as the wires unroll.

The reason for the use of the french word *fonction* is probably to make sure the patent would cover as many applications as possible. And it is indeed true that you could in principle make the vehicle follow quite complex directions on the way up.

The third part of the first sentence says that the wire control lasts until the launch vehicle is aerodynamically stable. The reference to *fixed tail fins* is translated from *empennage fixe* and the reference to *actively controlled aerodynamic surfaces* is from *empennage muni de volets stabilisateurs asservis*.

There is some uncertainty about the latter translation, so let us take a moment to discuss it. Input from readers is welcome.

The word *volet* generally means *flap* in relation to aeroplanes[36]. The word *asservis* means *enslaved* and so could indicate some kind of passive stabilization mechanism like rollerons to prevent spin or canted fins for generation of spin.

However, in technical usage *asservis* means *controlled* or *regulated*. In other words, there is an active element involved. This latter meaning is used in the translation. The word *asservis* is taken to indicates that an aerodynamic surface is controlled by active means.

A passive means of stabilization such as rollerons or canted fins seems unlikely for additional reasons.

1. Rollerons were first used on the AIM-9 Sidewinder missile[35] which flew for the first time in 1952[34], or 2 years after the patent was submitted.

2. Using spin for stabilization seems an unlikely method in combination with the Pilz wire guidance system because the wires would be twisted. It could perhaps work, but it does not appear to be a simple combination.

The lines or wires are introduced in the next 2 sentences. It is noted that at least 3 lines are required. Again, in order to make the patent cover as many applications as possible, it says *at least*, in french *au moins*, so the patent covers use of 3 lines, 4 lines, 5 lines, and so on.

Then we encounter again the word ”function”, now in the sentence about the length of each line being a *function of the length of the other lines*, or in french, *fonction de la longueur des autres fils*.

Again this may strike us as somewhat theoretical since we know in practical work this ”function” was one of the most simple functions available, that is, equality. That is because in practical use, the length of each of the wires was kept equal to the length of the other wires.

Thus we are led to assume that the use of the word ”function” is again made to keep the invention as general as possible.

Some readers may find figure 1 is misleading as it appears like the wires are fixed to firm points at the ground. Presumably the drawing is meant to illustrate the principle that wires are able to determine the direction of the *axis of the vehicle*, or in french *l'axe de l'engin*.

By the way, it may appear to the reader that the word *l'engin* means *the engine*, and it certainly could mean that. However, *l'engin* is also used in the phrase *to allow aerodynamic stabilization of the vehicle*, and here it would not make sense to say *aerodynamic stabilization of the engine*.

We now get to point b.

Once more we get in one single sentence what normally you would explain in multiple sentences.

At this point figure 2 is available to help us understand the text. It seems the drawing could be improved a little, but we get the point. The 3 lines unroll in sync with each other because they unroll from a common drum.

The text carefully says that the patent also covers a design whereby you have multiple drums. In that case the rotation of each drum must be made to agree *with that of the others*, or in french *les mouvements sont solidaires*. The french word *mouvement* could be translated *movement*, but is seems more natural to say *rotation* since we know that is the relevant kind of movement.

The sentence about the tension of the lines mentions an important point, which is that the tension may be established by the *inertia alone*. Today we would probably use an expression like *acceleration of the mass*. The word *inertia* has been used in agreement with the french *l'inertie*.

Just to make clear what we are talking about here, it is the second law of Newton,

$$F = m * a$$

which says that a certain force F, wire tension in this case, is required to provide on a mass m, the mass of the drum in this case, a certain acceleration a, which is in this case the acceleration of the launch vehicle.

It is relatively easy to see that the tension on the wires can be produced by means of a friction brake like the one on an automobile.

It is more interesting that the tension on the wires can be provided by the mass of the drum alone, because this simplifies the system, thereby making it less expensive to obtain the required reliability.

We will figure out how to compute the mass of the drum at page 21.

34. Wikipedia: ”AIM-9 Sidewinder”. Retrieved 2014-08-12.

35. Wikipedia: ”Rolleron”. Retrieved 2014-08-12.

36. Dassault aviation: ”Bilingual index”. Published on `www.dassault-aviation.com`. Retrieved 2014-08-12.

Wire length

As the launch vehicle rises from the launch pad, the wires from the Pilz guidance system pulls the drum to rotate faster and faster.

But surely there must be a limit to how fast it is safe to rotate the drum. If we spin it up to a high rotation frequency the bearings or the drum itself might break.

The length of the wires seem to play an important role here. If we use long wires, the drum will be spun up to a high rotation frequency.

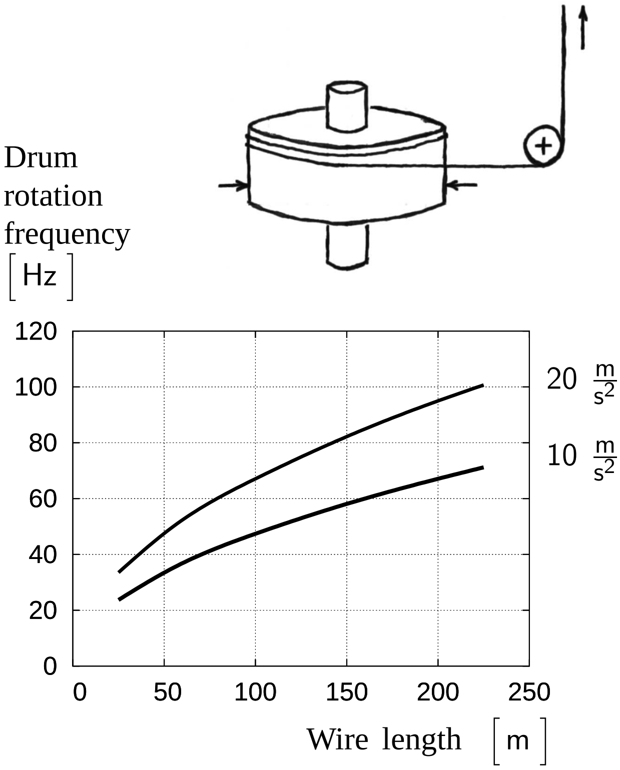
Suppose we figure out the speed of the launch vehicle first. That gives us the surface velocity of the drum. Then if we know the diameter of the drum, we can figure out the rotation frequency.

It seems fair to assume the launch vehicle has a constant acceleration in the first part of the flight, say the first 5 s to 10 s. With that assumption one of the basic kinematic equations[37] gives the velocity

$$v = \sqrt{2 * a * s}$$

where a is the geometrical acceleration and s is the distance travelled so far. The geometrical acceleration is the increase in velocity you might measure on a video of the launch. Inside the vehicle the passenger will experience an acceleration that is $9 \bullet 8 \ \frac{m}{s^2}$ higher due to the gravity of planet Earth.

For instance with the acceleration $a = 20 \ \frac{m}{s^2}$ and the distance $s = 200 \text{ m}$ we get $v = 89 \ \frac{m}{s}$.



This is the velocity of the launch vehicle, and it is also the surface velocity of the drum. But we really want to know the rotation frequency for the drum since that has implications for the bearings and the structural integrity of the drum.

To find that we need the diameter of the drum. Suppose we try with a diameter of $0 \bullet 30 \text{ m}$. The rotation frequency is

$$f = \frac{v}{\pi * d}$$

where d is the drum diameter. With $v = 89 \ \frac{m}{s}$ and $d = 0 \bullet 30 \text{ m}$ we get the rotation frequency $f = 95 \text{ Hz}$.

With a wire length of 55 m we get $v = 47 \ \frac{m}{s}$ and $f = 50 \text{ Hz}$.

Drum mass

Let us take a look at how you might figure out the mass required for the drum.

We consider the most simple case where the force on the wires comes from the acceleration of the mass of the drum. In other words, we do not consider using a friction brake for now.

It seems logical that a heavy drum will cause the wires to pull down on the launch vehicle more than a light drum.

Due to the wires, we see that the velocity of the launch vehicle and the velocity of the surface of the drum must be equal.

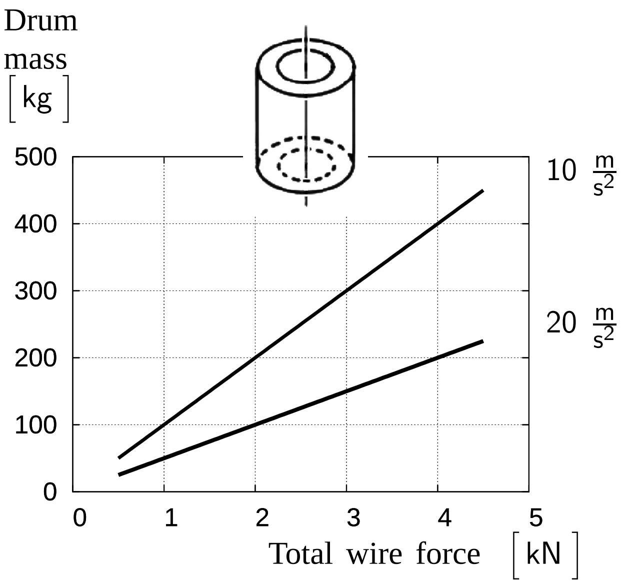
Because the velocities are equal, we see that the acceleration must also be equal. In other words, the acceleration of the launch vehicle is forced onto the drum so the acceleration of the drum is the same.

The launch vehicle pulls at the wires with a force and this causes the drum to accelerate to a higher and higher rotation frequency. We have

$$F = m * a$$

where F is the force, m is the mass of the drum, and a is the acceleration of the launch vehicle.

A small part of the power is lost in the bearings and in air friction. Let us assume we can ignore these losses.



Admittedly not all the mass of the drum is moving at the same velocity, but we will assume to begin with that the drum is formed as a hollow cylinder, so that most of the mass is approximately at the same velocity. On the next page we take a look at other kinds of mass distributions.

Suppose we have the launch vehicle geometrical acceleration $10 \ \frac{m}{s^2}$ and drum mass $m = 200 \ kg$. We then get the force on the wires $F = 2 \bullet 0 \ kN$. If we have 4 wires, this would be on average $0 \bullet 5 \ kN$ on each wire.

As another example, suppose we want a total force $F = 1 \bullet 0 \ kN$ on the wires and the geometrical acceleration of the launch vehicle is is $20 \ \frac{m}{s^2}$. We then need a drum mass of $m = 50 \ kg$.

Our calculations were so far based on an assumption that the drum has the shape of a hollow cylinder, or, in other words, that most of the mass will be accelerated to the drum surface velocity.

Let us now consider a solid cylinder. It could for instance be a hollow cylinder made of steel and filled with water. The rotational kinetic energy is[37]

$$E = \frac{1}{2} * moi * (2 * \pi * f)^2$$

where moi is the moment of inertia for the drum, and f is the rotation frequency. The moment of inertia for a solid cylinder is[37]

$$moi = \frac{1}{2} * m * r^2$$

where m is the mass of the cylinder and r is the radius of the cylinder. We insert this value in the first equation and get

$$E = \frac{1}{2} * \frac{1}{2} * m * r^2 * (2 * \pi * f)^2$$

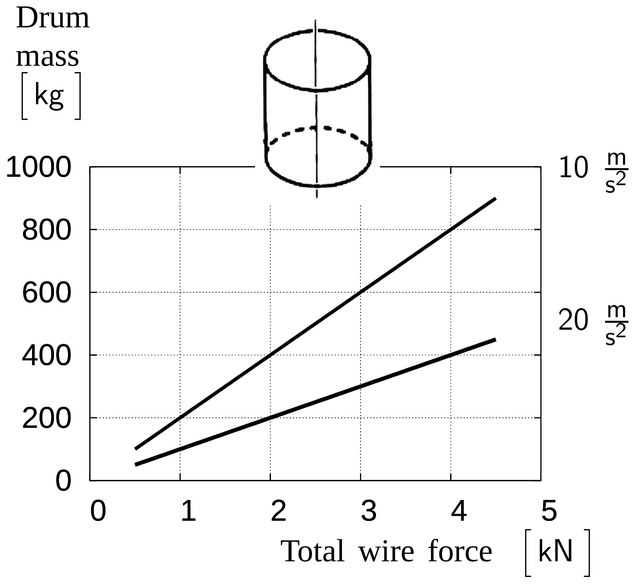
or

$$E = \frac{1}{2} * \frac{1}{2} * m * (2 * \pi * f * r)^2$$

and finally

$$E = \frac{1}{2} * \frac{1}{2} * m * v^2$$

We note that this is half the kinetic energy of a hollow cylinder, so apparently if we use a solid cylinder, it must have a mass 2 times as big as that of a hollow cylinder.



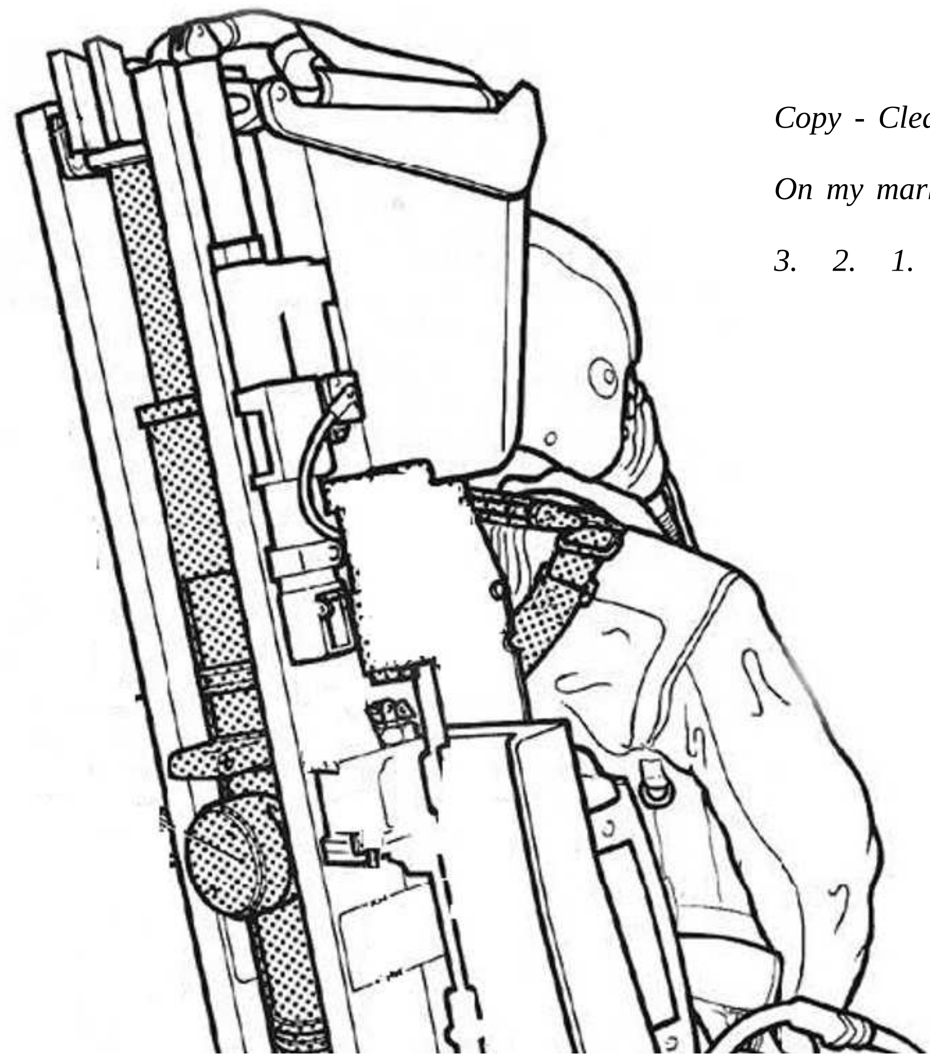
37. Graham Woan: ”The Cambridge handbook of physics formulas”. Published by Cambridge University Press, 2003.

Falling

PM. This is Ground Control.

Ejection checklist is complete.

You are cleared for ejection.

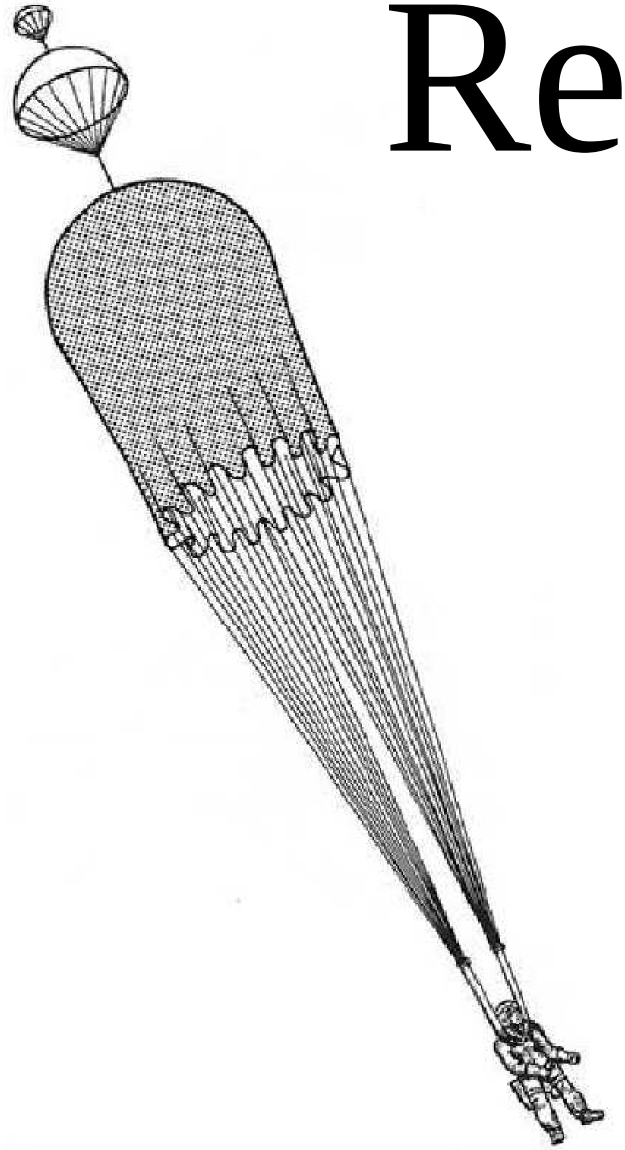


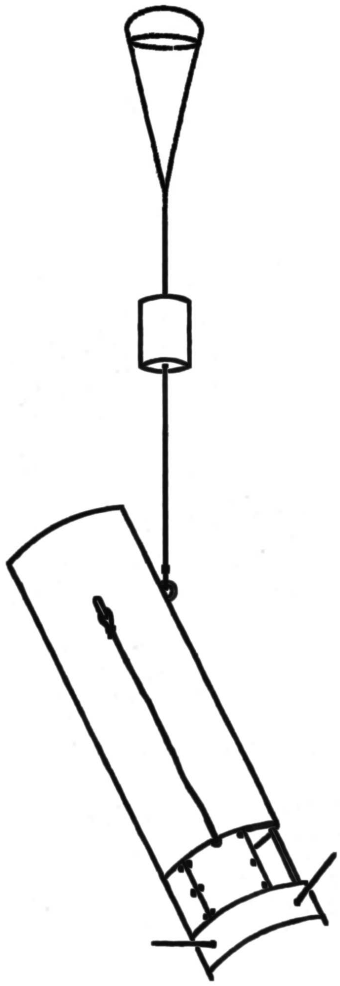
Copy - Cleared for ejection.

On my mark.

3. 2. 1.

Return





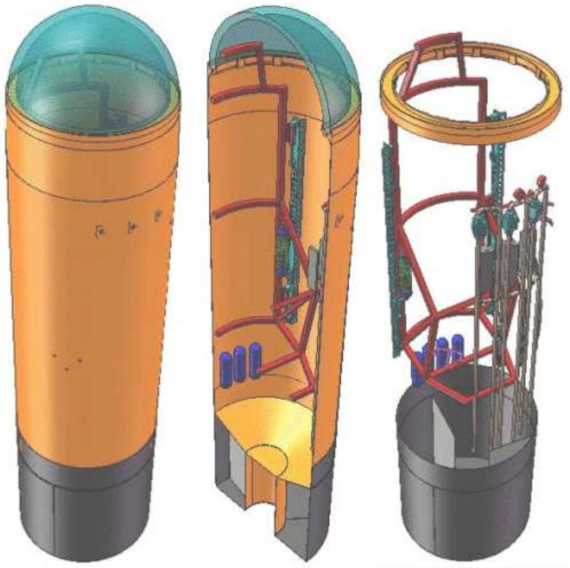
Kristian von Bengtson designed a *standing capsule*[29] in 2009 in a joint project with Peter Madsen. Later the *standing capsule* design was abandoned in favor of an Apollo-like capsule.

In the following years Peter witnessed a considerable growth in complexity, for instance with a launch escape system[30]. In the new 2014 project, he wanted to get back to a simple design[25].

> *We have seen in Copenhagen Suborbitals it is not a small task to develop a parachute system for a rocket or a capsule. Therefore it is my view that the shoestring solution is a commercial off the shelf parachute, also known as a personal parachute.*

Releasing the parachute in about 3 km altitude while in free fall at about 200 $\frac{\text{km}}{\text{h}}$ gives you a risk of injury at less than 1 in 50 000, he said. He added that getting to this level of reliability with a homebuilt parachute system for a capsule would be difficult and require extensive testing.

> *You get the bonus of a steering facility with a personal parachute. Released in* 4 000 m *altitude you can pick your landing location within a large area. This is also a safety bonus.*



Kristian von Bengtson designed a *standing capsule*[29] in 2009 in a joint project with Peter Madsen.

25. Peter Madsen: ”Så skal det handle om teknik!” In english, ”Time for technical talk!” Published on `ing.dk` 2014-06-21 15:07.

29. Kristian von Bengtson: ”Rumkapsel part 1 — grundlæggende konstruktioner og funktioner”. In english, ”Space capsule part 1 — basic design and functionality”. Published on `ing.dk` 2009-01-30 22:05.

30. Peter Madsen: ”Launch Escape System, faststof raket frit, tak!” In english, ”Launch Escape System, without solid propellant rocket, thanks!” Published on `ing.dk` 2011-07-17 13:09.

Comments and questions are welcome.

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