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[51] 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.*

Engine test burns were performed[41] on August 23, 2014.

Ignition failed at some occasions. Apparently the reliability of the consumable catalyst bed left something to be desired.

Peter Madsen in the following days experimented[42] with improvements to the consumable catalyst bed but did not find lasting improvement before the test engine suddenly exploded during a hard start[43] .

This debug work with the consumable catalyst bed made Peter Madsen consider using a traditional catalyst bed ahead of the combustion chamber[44] .

In august 2014 Peter Madsen began to consider[45,47] steel for the oxidizer tank. He mentioned S355, S500, and S700.

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.

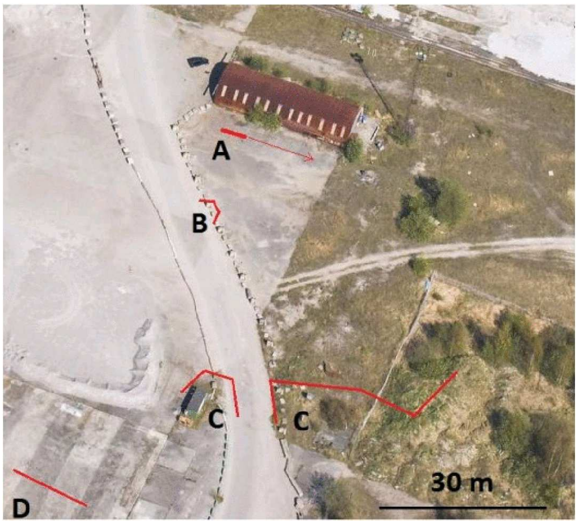
The downside is that you cannot get a high mass ratio with this system.

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.



Ready[46] for rocket engine testing at August 23, 2014. The Horizontal Assembly Building HAB is the red building in the top of the photograph. Zone A is the rocket engine test area. Zone B is the command area. Zone C is for photographic equipment. Zone D is for the audience.

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.

41. Peter Madsen: ”Lørdagens tests og chockdiamanter fra RML!” In English, ”The tests of saturday and shock diamonds from RML!” Published on ing.dk 2014-08-24 15:20.

42. Peter Madsen: ”Femte test af SuperHATV motoren — nu med forbedret tændsats”. In English, ”Fifth test of the SuperHATV motor — now with improved igniter”. Published on ing.dk 2014-08-25 13:29.

43. Peter Madsen: ”XLR3B-2”. Published on ing.dk 2014-08-28 11:54.

44. Peter Madsen: ”Jernbeton. Masser af jernbeton”. In English, ”Reinforced concrete. Lots of reinforced concrete”. Published on ing.dk 2014-08-30 15:25.

45. Peter Madsen: ”Kan man have T-stoff i en ståltank?” In English, ”Will it work with T-stoff in a steel vessel?” Published on ing.dk 2014-08-17 18:36.

46. Peter Madsen: ”Oprustning på Refshaleøen”. In English, ”Armament on Refshaleøen”. Published on ing.dk 2014-08-06 23:56.

47. Peter Madsen: ”Der regnes, tegnes og bygges på livet løs!” In English, ”Calculation, drawing, and fabrication at full power!” Published on ing.dk 2014-08-02 01:47.

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

Decomposition

Usually rocket engines decompose H_2O_2 by catalysis before it is injected into the engine. In this way H_2O and O_2 is injected instead of H_2O_2.

It is known that H_2O_2 will decompose when heated. It has therefore been considered to use thermal decomposition of H_2O_2 instead of catalytic decomposition.

This can be done in a decomposition chamber before the combustion chamber, or it can be done in the combustion chamber.

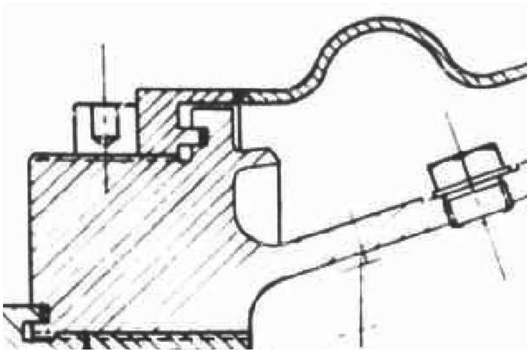
Let us first consider doing thermal decomposition in a decomposition chamber before the combustion chamber.

According to the classic Rocketdyne *Hydrogen Peroxide Handbook*[826] thermal decomposition cannot be used in a self-sustaining way[1].

> *The use of self-heating thermal chambers to maintain controlled decomposition of hydrogen peroxide has been limited to laboratory studies.*

Experiments concluded that[1]

> *the slow rate of thermal decomposition of hydrogen peroxide cannot compete with the rates obtainable with catalytic decomposition.*



Detail from a regeneratively cooled combustion chamber[3].

Schumb et al says that although in principle[2]

> *decomposition could be obtained by a purely thermal method (...) the problems of reliable start-up and operation have always led in practice to the use of catalyst, except where direct reaction with a self-igniting [hypergolic] fuel has been used.*

1. See the classic Rocketdyne *Hydrogen Peroxide Handbook*[826] page 433, pdf page 452.

2. See Schumb et al[2682] page 109, pdf page 119.

3. The drawing is from one of the documents[2955] about German rocket technology in 1935 to 1945, pdf page 102.

826. Cain, E F C et al: ”Hydrogen peroxide handbook”. Published by Rocketdyne and U S Air Force as AFRPL-TR-67-144, USA, July 1967.

2955. Anon: ”Analysis and evaluation of German attainments and research in the liquid [propellant] rocket engine field. Volume IV. Propellant injectors”. Published by Central Air Documents Office (Army - Navy - Air Force), USA, February 1952.

2682. Schumb, W C, et al: ”Hydrogen peroxide. Part four. Report no. 45”. Published by Massachusetts Institute of Technology as NR-092-008, USA, November 1953.

Decomposition

The United States Missile Defense Agency in 2003 proposed a project[1] to figure out how thermal decomposition of H_2O_2 could be used.

It seems the agency was open to both kinds of thermal decomposition, that is, both in a chamber for itself, and in a combustion chamber.

The agency said in the proposal that hydrogen peroxide is normally

> *passed over a catalyst bed to decompose it prior to entering the main combustion chamber*

but the agency

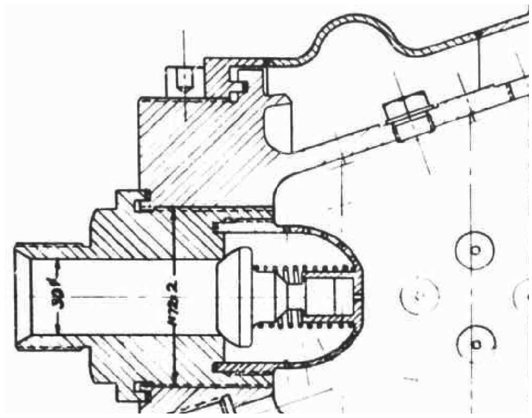
> *seeks alternative techniques for decomposing HTP*[2]

The agency said that

> *the only other documented decomposition mechanism is thermal*

but

> *past attempts at employing thermal decomposers frequently resulted in catastrophic failure*



Detail from a regeneratively cooled combustion chamber[3] .

1. See the Small Business Technology Transfer Program[2692] page 8.

2. HTP is short for *high test peroxide* which means a mixture of H_2O_2 and H_2O where the concentration of H_2O_2 is close to 100 per cent.

3. The drawing is from one of the documents[2955] about German rocket technology in 1935 to 1945, pdf page 102.

2955. Anon: ”Analysis and evaluation of German attainments and research in the liquid [propellant] rocket engine field. Volume IV. Propellant injectors”. Published by Central Air Documents Office (Army - Navy - Air Force), USA, February 1952.

2692. Anon: ”Missile Defense Agency (MDA) small business technology transfer program (STTR)”. Published by the Missile

Defense Agency, USA, presumably in 2003.

The vehicle

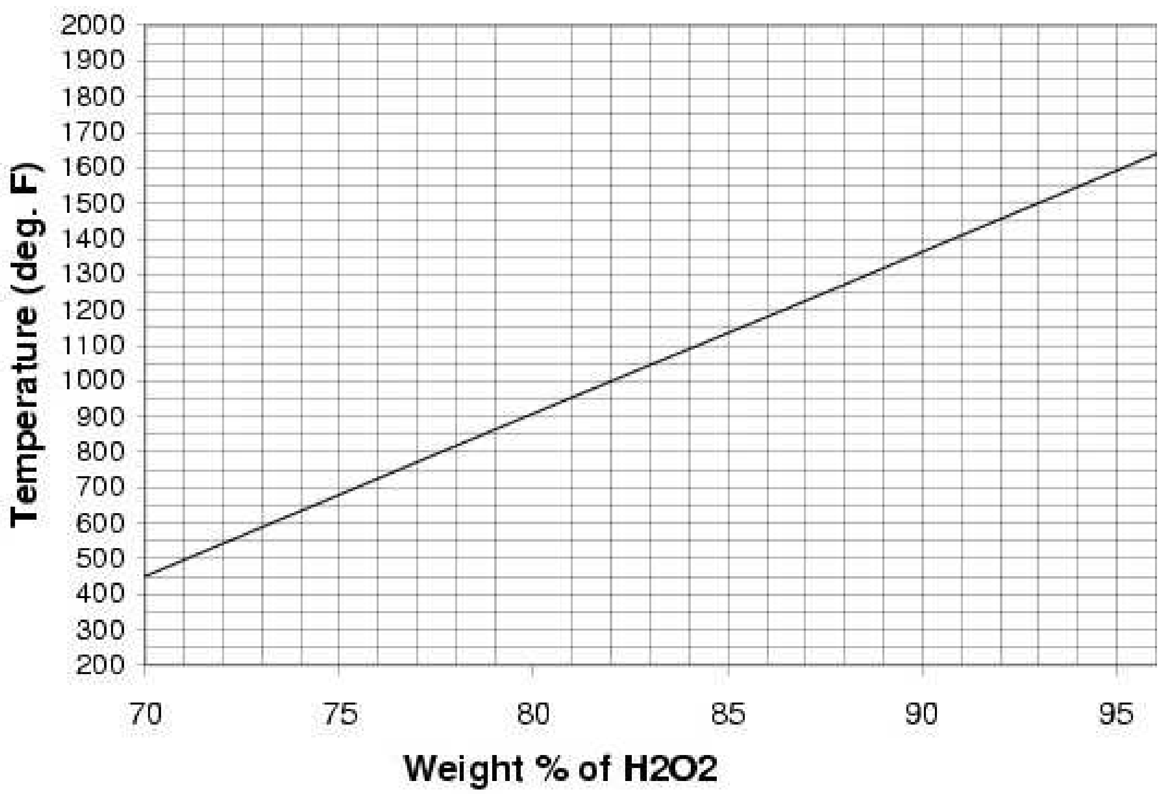
Launch mass[9]	2•0e3 kg
Vehicle diameter[40]	0•64 m
Motor type[51]	Hybrid
Grain geometry[6,3]	Wagon wheel
Grain ports[6,3]	9
Throat diameter[6] d_t	200 mm
Combustion chamber pressure[6] P_c	16 bar or 1•6 MPa at lift-off
Thrust coefficient[6] C_f	1•3
Throat area[6,7] A_t	314 cm^2 or 31•4e−3 m^2
Pressurization system[51]	Pressure-fed
Ignition system[1]	Consumable catalyst bed
Ignition system[2]	Pellet $KMnO_4$ catalyst bed
Oxidizer tank wall thickness[47]	3•0 mm if steel

Table continued at the next page.

Fuel[5,2943]	Solid polyurethane ”Edulan Purteknik 1133 sort”
Fuel tensile strength[2942]	$7 \bullet 9$ MPa according to ISO 527
Fuel density[2942]	$1\ 110\ \frac{kg}{m^3}$ according to ISO 2781
Fuel[6]	168 kg
Oxidizer[51]	80 per cent H_2O_2
Oxidizer[6]	840 kg
Expected ISP[6,40]	180 s to 190 s
Expected exhaust velocity[8]	$1 \bullet 76\ \frac{km}{s}$ to $1 \bullet 86\ \frac{km}{s}$
Oxidizer flow at lift-off[6]	$29\ \frac{kg}{s}$
Propellant flow at lift-off[6] $\frac{dm}{dt}$	$34 \bullet 8\ \frac{kg}{s}$
Thrust at lift-off[6,7,8] F	62 kN

Notes on the following pages.

1. Ignition. The theoretical decomposition temperature of 80 per cent H_2O_2 is[10] about 750 K or 480 C. In an engine it will take some time for the catalyst bed to heat up. At ignition time the temperature will therefore be lower than 750 K.



Decomposition temperature of H_2O_2 as a function of concentration[10].
450 F is 505 K or 232 C.
900 F is 755 K or 482 C.

1. Continued from the previous page. The consumable catalyst bed was the ignition device to be used in the beginning of the project. After the problems on August 27, 2014, it seems less likely this type of ignition device will be used.

2. It is not quite right to call a catalyst bed an ignition system, so here is an explanation.

The idea is that ignition will occur automatically if the 80 per cent H_2O_2 is decomposed in a $KMnO_4$ catalytic pellet bed before it is injected into the combustion chamber with solid polyurethane.

The temperature of the mixture of H_2O gas and O_2 gas is about $750\ K$ or $480\ C$. The melting point of polyurethane vary considerably with the kind of polyurethane. One kind of polyurethane melts at $564\ K$ or $291\ C$. See the polymer data handbook[172] page 879, pdf page 969. The warm H_2O and O_2 gas is therefore about $200\ K$ above the melting point of the polymer. Therefore the polymer will melt in the surface layer.

This kind of polymer begins to decompose when it melts. It does not become liquid. So it gives off various gases, presumably mostly made of carbon and hydrogen. The question is now if some of those substances can be ignited.

The autoignition temperature of some of the organic substances given off by the decomposing polyurethane is less than $750\ K$, for instance $638\ K$ or $365\ C$ for ethanol[4] .

3. The center of mass stability of the vehicle in relation to the grain geometry has not yet been addressed.

4. Wikipedia: Ethanol.

5. Peter Madsen: Email 2014-09-03.

6. Peter Madsen: Email 2014-08-26.

7. The rocket engine thrust is

$$F = C_f * A_t * (P_c - P_a)$$

where C_f is the thrust coefficient, A_t is the throat area, P_c is the combustion chamber pressure and P_a is the ambient pressure.

With $C_f = 1 \bullet 3$, $A_t = 314\ cm^2$, $P_c = 16\ bar$, and $P_a = 1 \bullet 0\ bar$ we get $F = 61\ kN$.

With $C_f = 1 \bullet 3$, $A_t = 31 \bullet 4e{-}3\ m^2$, $P_c = 1 \bullet 6\ MPa$, and $P_a = 0 \bullet 10\ MPa$ we get $F = 61\ kN$. 8. The exhaust velocity is $V_e = g * ISP$ where g is the acceleration of Earth. The engine thrust is

$$F = V_e * \frac{dm}{dt}$$

With $V_e = 1 \bullet 76\ \frac{km}{s}$ and $\frac{dm}{dt} = 34 \bullet 8\ \frac{kg}{s}$ we get $F = 61\ kN$.

9. The launch mass is calculated from the an assumption of a geometrical lift-off acceleration of $20\ \frac{m}{s^2}$. We have

$$F = m * (ag + g)$$

where F is the engine thrust at lift-off, ag is the geometrical acceleration, and g is the acceleration of gravity on the planet. We find the launch mass is

$$m = \frac{F}{ag + g}$$

With $F = 61\ kN$, $ag = 20\ \frac{m}{s^2}$ and $g = 9 \bullet 8\ \frac{m}{s^2}$ we get $2 \bullet 0e3\ kg$.

10. The decomposition temperature graph is from Ventura and Wernimont[2638] page 4.

40. Peter Madsen: ”Ny hybrid motor, nu med Fessor II katalysator”. In English,

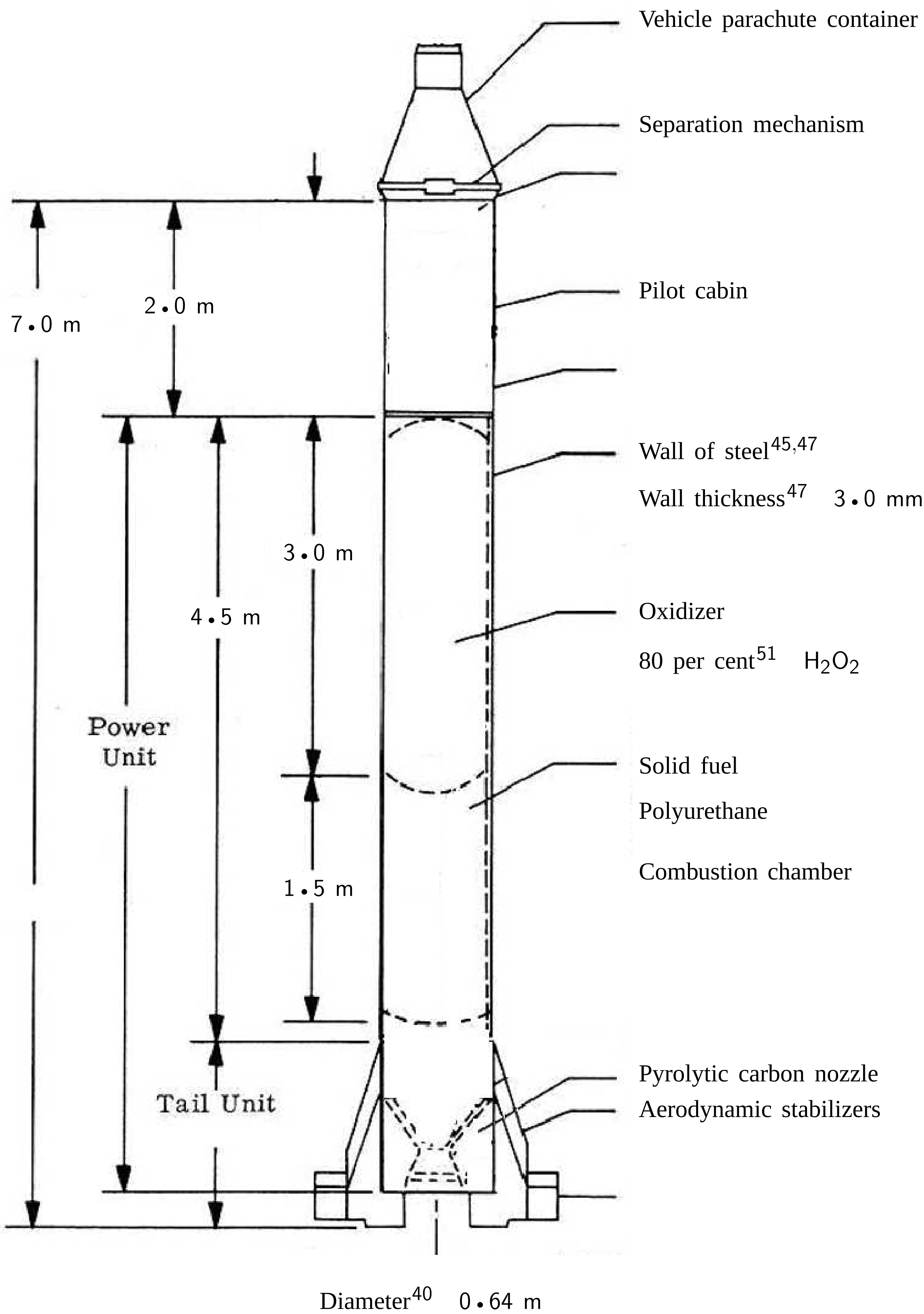
”New hybrid motor, now with Fessor II catalyst bed”. Published by ing.dk 2014-09-02 13:43.

172. Mark, James E: ”Polymer data handbook”. Published by Oxford University Press, Inc, october 1998.

2638. Ventura, M C and Wernimont, Eric J: ”Advancements in high concentration hydrogen peroxide catalyst beds”. Published by AIAA as AIAA-01-3250, USA, July 2001.

2942. Datablad. Purteknik 1133 sort. Published by Edulan A/S, Denmark, June 2002.

2943. Sikkerhedsdatablad. Edulan Purteknik 1133 sort. Published by Edulan A/S, Denmark, 2003-03-24.


Vehicle parachute container
Separation mechanism
Pilot cabin
Wall of steel[45,47]
Wall thickness[47] 3.0 mm
Oxidizer
80 per cent[51] H_2O_2
Solid fuel
Polyurethane
Combustion chamber
Pyrolytic carbon nozzle
Aerodynamic stabilizers
7.0 m
2.0 m
3.0 m
4.5 m
1.5 m
Power Unit
Tail Unit
Diameter[40] 0.64 m

40. Peter Madsen: ”Ny hybrid motor, nu med Fessor II katalysator”. In English, ”New hybrid motor, now with Fessor II catalyst bed”. Published by `ing.dk` 2014-09-02 13:43.

45. Peter Madsen: ”Kan man have T-stoff i en ståltank?” In English, ”Will it work with T-stoff in a steel vessel?” Published on `ing.dk` 2014-08-17 18:36.

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