Development of Low Cost Propulsion Systems for Micro-Satellite Launch Vehicles

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The preliminary design of a Micro Satellite Launch Vehicle is presented (payload capacity: 70 – 75 kg to LEO). Several propellant / stage combinations are discussed (Liquid Oxygen (LOX) / Ethanol (EtOH) respective Hydrogen Peroxide (HTP) / EtOH).
Using 95 % HTP / EtOH in upper stages does result in a comparable performance to LOX / EtOH considering the payload achieved and is likely to lead to an increased operational reliability.

Low cost propulsion is one key component to build a low cost launcher. At present, WEPA-Technologies is developing an expendable, low cost propulsion unit (35 kN liquid propellant rocket engine (LPRE) and corresponding turbo pump unit (TPU)). Potential uses could be in Micro Satellite Launch Vehicles or booster applications for sounding rockets.
Considering the very popular use of solid propellant booster stages in sounding rockets, a substitution by LPRE stages would result in an improved variability of payload size and maximum altitude. Additionally, liquid propulsion systems would help to avoid many of the safety and legal restrictions connected with handling of solid propellants.

The development of a mobile production plant enabling on customer's site the production of HTP (max. 97 %) is described. World wide operation of the plant by WEPA personnel is possible. The availability of a mobile production plant would be very helpful, as HTP in excess of 88 % may not be transported on public ground and has to be produced on site.

1. Micro Satellite Launch Vehicle

<u>Is there a demand?</u>

Today's standard launch services for micro satellites are being conducted via secondary payload rides. In the course of this procedure, the micro satellite is being carried together with a much larger (and significantly more expensive) satellite. Therefore, launch fees due for each satellite vary significantly. Needless to mention, that important launch parameters are fully tailored to meet the needs of the more expensive payload in terms of launch schedule and orbit.
Besides that, lead time required until launch date usually is in excess of one year and significant restrictions concerning the nature of the secondary payload do exist. "Responsiveness" in terms of short lead time to launch therefore is unavailable.
A very significant percentage of secondary flight opportunities are offered by non European agencies: the development of a European Micro Satellite Launch Vehicle would significantly facilitate an independent access to space for this class of satellites.
Considering the promising uses of micro satellites and growing number of organizations developing them [2], we are convinced of a significant demand for low cost, primary payload flights!

<u>Low cost approach</u>

Besides reliability, the most important issue for a personalized launch opportunity are low costs.

Our approach concerning propulsion units is based on proven technologies successfully used in flight vehicles of the pioneer era in the USA and former USSR. A decent upgrade by modern standard construction materials and production technologies is desirable, but modern 'high performance materials' are to be avoided. Furthermore, the use of standard, mass production parts should be preferred, while key components should be manufactured in house.

Key points of the launch vehicles do encompass the following issues:

- Designed to use three stages in order to avoid high performance propulsion units and advanced vehicle construction issues as required when using a two stage approach.
- Maximum possible use of identical parts in all stages.
- Preference of numbering up or clustering of propulsion technology instead of scale up.
- Use of pressure fed, re-startable propulsion systems in stage 3 to improve orbital insertion capabilities.
- Environmentally friendly, easy to handle fuel combinations (LOX, HTP, EtOH). This helps to significantly drive down costs during storage, filling and general handling procedures during all stages of systems life cycle.

<u>Conceptional Design</u>

For the present design study, we did consider a payload range of 50 – 100 kg, as this is common for many Micro Satellite projects. Due to the present design study being of a general nature, we did focus on an average value, i.e. 70 – 75 kg to be delivered to LEO. The nature of the payload is preferably a Micro Satellite, but any other kind of equipment could be chosen as well.

We define LEO to the point of reaching a final upper stage velocity of at least 7,5 km / s – as we did not conduct any detailed aerodynamic and trajectory optimization, the calculation of individual stage velocities has been performed by using the ideal rocket equation. To compensate for the inevitable losses due to drag and gravity, additional 2,0 km / s were added (minimum velocity to enter LEO therefore added up to 9,5 km / s).

It has to be re-stated, that the design is driven by low cost and not by performance contrary to the preferred approach in industry!

The propulsion base case does use LOX and EtOH. While LOX is a well proven oxidizer present in the rocket business since the very beginning, it still has some specifics of its own to be considered: evaporative losses during pre-operation time, isolation requirement (tanks, pumps, sensors), chill down requirements of engine and turbo pump unit and reliability issues concerning ignition of upper stages within vacuum [1,3].

To avoid the specific challenges coming along with LOX, the use of hydrogenperoxide (HTP, 85 %, 95 %) is considered. Following established safety procedures HTP is safe to use [4,5,6] and does exhibit the advantages listed below. They are especially promising when using HTP in upper stages:

- storability / no evaporative losses during pre-operation time
- simplified, non cryogenic feed system (turbo pump unit resp. pressure feeding)
- no chill down procedure of the system prior to ignition required
- reliable, effectively "hypergolic" ignition process

The points listed result in a significantly reduced degree of system complexity and increased operational reliability. Consequently, multiple burn periods are possible: this will result in an advantage to achieve more precise orbital insertion of payloads or even realize different orbital heights for delivering multiple payloads.

The advantages listed for using HTP in upper stages for sure are accessible while using other storable propellant combinations as well: one very common example are dinitrogentetroxide / hydrazine derivatives (e.g. UDMH). Both propellants are highly toxic and thus require extensive safety protocols to be followed. This drives up system costs very significantly. All those disadvantages can be avoided by using HTP based upper stage systems.

Conceptional Design

To assure general comparability of the different design cases the outer envelope of each stage and inert mass has been kept constant. Dimensions and weight were determined by first calculating a launcher using LOX / EtOH in all stages. (Base case definition.)
Propulsion parameters used are listed in table 1.

Results

The results of specific design cases are summarized in table 2. The only modification has been the exchange of the oxidizer. (Individual tank volume ratios were adjusted to account for changing oxidizer / fuel ratios, while the total tank volume of both components was kept constant.)
Interpreting the results the following conclusion can be made:

- the payload projected (70 – 75 kg to LEO / *v* = 7,5 + 2,0 = 9,5 km / s) can be realized by using different oxidizer / stage combinations.
- Payload wise using HTP 95 % is equivalent to LOX, but comes along with significant advantages (reduced system complexity / increased operational reliability [1,3])

Gross lift off weight (GLOW) is calculated between 11,0 – 13,7 t – the payload percentage between 0,52 - 0,65 %. As these numbers are lower than state of the art, it should be kept in mind, that it results from a low cost, not high performance design approach!

Interpreting table 3 does result in another conclusion:

- increasing HTP concentration from 85 to 95 % will result in an payload increase of 41 %
- only the use of HTP in a concentration of 95 % will result in a performance comparable to LOX (payload considered).

The most suitable propellant system certainly is depending on specific boundary conditions as e.g.:

- availability of propellants
- prior experience in engine development and handling
- storability issues
- preference of the development team and / or organization

2. Current Development Activities

We consider low cost propulsion systems as one key component to realize low cost Micro Satellite Launch Vehicles.
Low cost propulsion systems can be achieved as follows:

- simplified design of rocket engines and turbo pump units
- focussing on expendable systems
- low level operational parameter (chamber pressures, temperatures, RPM of TPU)
- use of low cost materials and manufacturing technologies
- unification of design of propulsion systems of first and second stage via clustering (applicable if identical propellant systems are used!)

WEPA-Technologies is developing turbo pump feed systems and thrust chambers. At present, the development of a 35 kN LPRE / TPU as a technology demonstrator is commencing.
Details of both developments are mentioned below.

Turbo Pump Unit

General remarks

There are two universities involved in the development of the TPU:

- Technical University of Dresden (Chair for Space Systems: Prof. Tajmar / Dr. Przybilski); 2014

- University of Applied Sciences Cologne
  (Institute for Product Development and Construction Technology: Prof. Mueller), 2012

Design parameter

The main goal is to create a design minimizing engineering, manufacturing and testing effort. Therefore, low level operational parameters are used. Key points of the TPU are summarized as follows:

- Propellant system:
  LOX / EtOH resp. HTP / EtOH
- Total mass: ~ 35 kg
- Arrangement: Turbine – EtOH – Oxidiser
- Gas generator (open cycle)
- Exit pressure: 7,5 MPa
- Max. 30,000 RPM

Status

Detailed construction in progress – completion is expected in September 2014.
Manufacturing will be mainly conducted in WEPA-Technologies workshop. (August – Dezember 2014)
Start of prototype qualification will commence in December 2014. After completion of qualification, an improved TPU version will be built and tested.

<u>Development of LPRE</u>

In order to manufacture low cost engines, a significant reduction of development and production costs is required. One option to achieve that goal is to improve designs based on technologies of the pioneer years (USA & former USSR (1950 – 1970)). An important issue is to focus on designs showing the potential to enable cheap series production.
The use of “green propellants” causing no significant issues to the test and launch area or operating personnel are important as well (LOX, HTP, EtOH).
At present, engines within a thrust range between 10 – 60 kN are under consideration at WEPA-Technologies. The mid term goal is an increase up to a range of 100 – 200 kN. All mentioned engines do have potential applications in sounding rockets, launch vehicles and defence (air, land, naval).

Current development activities

At present, a 35 kN LPRE / TPU is being developed (technology demonstrator).
Key parameters are as follows:

- chamber pressure: 5 MPa
- nozzle exit pressure: 0,05 MPa
- LOX /EtOH ; HTP / EtOH
- O/F ratio adjusted to maximum Isp

Using a swirl type injector is projected. Regenerative cooling is applied. The choice of cooling media used depends on the oxidizer / mixture ratio used: EtOH in case of LOX and HTP in case of HTP, respectively.
To reach cost reduction potentials, technologies enabling series production will be used (welding, brazing).

<u>Development of a booster stage (Suborbital Launch Vehicle)</u>

A Micro Satellite Launch Vehicle preferably would be developed in an incremental process. Our preferred approach is using stage 2 to develop and validate key technology components as propulsion and guidance. Besides the mere goal to develop a component of the Micro Satellite Launch Vehicle, using this stage for booster purposes in other projects seems to be a logical approach.

This approach would have the following advantages:

- adaptation of the liquid propellant booster unit – i.e. stage 2 of the Micro Satellite Launch Vehicle – to the payload and system section of existing sounding rocket projects would possibly increase the flight apex / zero-g time or payload capacity of the existing systems.
- Only the (existing) booster section would have to be exchanged against the new one. Qualified equipment or even the complete payload section could be reused (data acquisition, data downlink, power

supply, telemetry, recovery). This should significantly decrease the effort needed to increase the abilities of the sounding rocket.
- Substituting solid propellant containing booster by those using liquid propellants would decrease safety and legal restrictions significantly.
- Sounding rocket projects would no longer be depending on surplus military booster.

First simulation results of a Suborbital Launch Vehicle / sounding rocket using stage 2 are presented in diagram 1.
Using a payload capacity of 100 kg, the flight apex would be at 265 km.
Final adjustment of propulsion system and payload can only be achieved in a joint effort of booster manufacturer and sounding rocket operator.

3. Supply of HTP (c > 88 %)

General remarks

As discussed before, a Micro Satellite Launch Vehicle using HTP in upper stages is likely to significantly increase its operational reliability. Considering the payload capacity, a concentration increase from 85 to 95 % enables an identical performance to a launcher using LOX only and having an identical envelope (refer to section 1 for further details.).
HTP is safe to use when following well documented, basic safety procedures [4,5,6].

Commercial supply situation

The commercial supply situation at present unfortunately is characterized by a very limited availability of HTP with c > 88 %. (This is valid even for small laboratory quantities!). The reason are legal restrictions governing the transport on public ground. As a consequence, only an on site production may be realized.
The concentration process of HTP in this range comes along with several safety issues, but can be handled very safe in case proper process design and plant setup have been realized. But the development of such a plant is a major, long term project of its own and does require extensive knowledge in chemical engineering technology and plant construction. Consequently, this is not an option for most of the companies or institutions having a need for this material.
Small production plants starting from 70 – 85 % HTP can be supplied by some of the major HTP producers – a rental is not possible. To the authors best knowledge, the costs for a small capacity production plant (1 kg / h) start around 1,8 Mio EUR. Therefore, it is easy to anticipate why this is not the first choice for meeting the demand of very high concentration HTP.

Development of a mobile concentration unit

In cooperation with an external partner, WEPA-Technologies develops a very safe, automated, low temperature concentration technology yielding a maximum concentration up to 97 %! The feedstock concentration is between 60 – 85 %. In order to serve external customers at their sites, the production plant will be mobile and fitting into a car trailer.
Production capacity will be about 10 kg/h – the only utilities the customer has to provide will be electricity (400 V / 16 A) and cooling water.
Serving customers at any location world wide will be possible, in case compliance with EC export regulations can be realized. (The plant will be exclusively operated by WEPA personnel.)
At present, lab scale validation of the production process is commencing.
The timeline for completion of the mobile, full capacity plant depends on market demand / customer requests.

Applications of HTP

Numerous applications of HTP are possible:
- booster and upper stage propulsion (launch vehicles and sounding rockets)
- position control
- gas generators

- defence (air, land, naval)

Customer requests are welcome!

4. Summary

The preliminary design of a Micro Satellite Launch Vehicle has been presented (payload capacity: 70 – 75 kg to LEO). Several propellant and stage combinations have been discussed (LOX / EtOH, HTP / EtOH).
The specified payload could be delivered by using a three stage design with 11,0 – 13,7 t GLOW and 15,3 m total height.
Using 95 % HTP / EtOH yields a payload capacity comparable to LOX / EtOH and is likely to result in increased operational reliability.

Low cost propulsion is a key component to build a low cost launcher. Presently, WEPA-Technologies is developing a low cost 35 kN LPRE and corresponding turbo pump unit (LOX / EtOH resp. HTP / EtOH).
Besides potentially being used in a Micro Satellite Launch Vehicle, the 35 kN demonstrator unit could be used in booster applications for sounding rockets. Compared to the very popular use of solid propellant booster stages, a substitution by LPRE would result in an improved variability of payload size and maximum altitude. Furthermore, avoiding pyrotechnic solid propellants would result in much lower safety standards to be followed respectively legal issues to be deals with.

The development of a mobile production plant - enabling the production of HTP (max. 97 %) on customer’s site has been described. World wide operation of the plant by WEPA personnel is possible.
The availability of a mobile production plant is desirable, as HTP in excess of 88 % may not be transported on public ground and has therefore to be produced on site.

5. References

[1] Andrews, D., “Advantages of Hydrogen Peroxide as a Rocket Oxidant”, Journal of the British Interplanetary Society., Vol. 43, 1990, 319

[2] Caceres, M., “Expanding Customer Base for Space Payloads”, Aerospace America, 09/2013, 22

[3] Musker, A.J., Rusek, J. J., Kappenstein, C.; Roberts, G.T., “Hydrogen Peroxide – from Bridesmaid to Bride”, 3rd ESA International Conference on Green Propellants for Space Propulsion, Pointiers, Frace, 09/2006

[4] Rocketdyne, NAA, “Hydrogen Peroxide Handbook”, AFRPL-TR-67-144, Air Force Rocket Propulsion Laboratory, Edwards AFB, 1967/07

[5] Ventura, M. C., Durant, D., “Field Handling of Hydrogen Peroxide”, AIAA2004-4146, 07/2004

[6] Ventura, M., Wernimont, E., Heister, S., Yuan, S., “Rocket Grade Hydrogen Peroxide for use in Propulsion and Power Devices – Historical Discussion of Hazards”, AIAA 2007-5468, 07/2007

A. Introduction to WEPA-Technologies:

WEPA-Technologies GmbH has been founded in 2011 as a spin-off. Its business activities before that time were embedded in a specialised mechanical engineering company.

WEPA focuses on Engineering-, Automation- and Aerospace-Solutions. Aerospace Solutions at present mainly focus on rocket technology related issues and highly profit from the companies' extensive expertise in several engineering fields and automation technology.

The company profile can best be described as research and development focussed engineering office with prototype- and small series manufacturing capacities.

Available workshop capabilities on 700 m^2 floor area do encompass a broad range of manufacturing technologies in CNC- (turning, milling, wire eroding) and conventional machining (grinding., welding).

References include Airbus Defence & Space (CASSIDIAN GmbH) (development of a solid rocket motor) and Dynamit Nobel Defence GmbH.

B. Business Activities

Rocket Technology

The activities are focussed on the development and manufacturing of propulsion technology i.e. LPRE including thrust vector control, turbo pump units (TPU) and solid rocket motors.
Complete systems, i.e. suborbital rocket stages, are under development.

Engineering

Construction and manufacturing of mechanical parts.

Automation

These activities are focussed on control retrofits of CNC-machine tools.

Table 1
Propulsion parameter (Micro Satellite Launch Vehicle design study)

Stage	Thrust	Pressures			Efficiency	Isp		
						LOx /	H2O2 (85 %)	H2O2 (95 %) /
		p(chamber)	p(nozzle exit)	p(ambient)		EtOH (96%)	EtOH (96%)	EtOH (96%)
[-]	[kN]	[MPa]	[MPa]	[MPa]	[%]	[s]	[s]	[s]
1	4 X 35	5	0,05	0,1	95	255	227	237
2	1 X 35	5	0,005	0,005	95	313	278	292
3	1 X 10	1	0,001	0,001	95	310	278	291

(calculated via RPA-Software)

Table 2
Performance summary of selected design cases (Micro Satellite Launch Vehicle design study)
Effect of increasing exchanging LOX by HTP.

Stage	Propellant combinations			
	(fuel: all stages **EtOH**)			
1	LOX	LOX	LOX	H2O2 85 %
2	LOX	LOX	**H2O2 95 %**	**H2O2 95 %**
3	LOX	**H2O2 95 %**	**H2O2 95 %**	**H2O2 95 %**
GLOW [t]	11,0	11,0	11,3	13,7
Payload (LEO) [kg]	**72**	**73**	**72**	**71**
Payload (LEO) [% GLOW]	0,65	0,66	0,64	0,52

H2O2 driven upper stages:
reduced system complexity / increased operational reliability !

Table 3
Performance summary of selected design cases (Micro Satellite Launch Vehicle design study)
Effect of increasing HTP concentration on payload (85 % => 95 %)

Stage	Propellant combinations				
	(fuel: all stages **EtOH**)				
1	LOX	LOX	LOX	H2O2 85 %	H2O2 85 %
2	LOX	H2O2 85 %	**H2O2 95 %**	H2O2 85 %	**H2O2 95 %**
3	LOX	H2O2 85 %	**H2O2 95 %**	H2O2 85 %	**H2O2 95 %**
GLOW [t]	11,0	11,2	11,3	13,7	13,7
Payload (LEO) [kg]	**72**	**51**	**72**	**50**	**71**
Payload (LEO) [%]	0,65	0,46	0,64	0,36	0,52

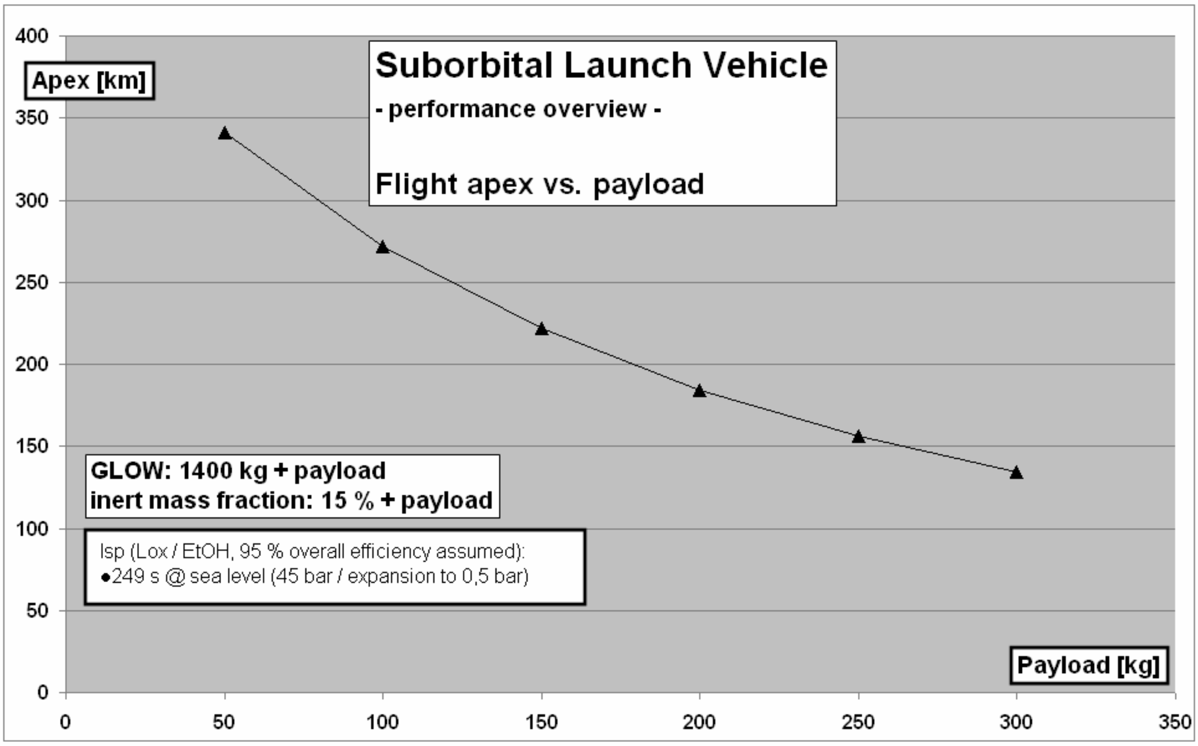

Diagram 1

Apex of Suborbital Launch Vehicles equipped with payloads between 50 – 300 kg.

Development of Low Cost Propulsion systems for Micro-Satellite Launch Vehicles

Space Propulsion 2014

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WEPA-Technologies GmbH

WEPA Technologies

Overview

- **WEPA-Technologies GmbH**
  - **Introduction**
  - **Business activities**
- **Project 'Micro Satellite Launch Vehicle'**
  - **Is there a demand ?**
  - **Low cost design**
  - **Preliminary concept**
  - **First simulation results**
- **Current development activities**
  - **Turbo Pump Unit**
  - **Liquid Propellant Rocket Engine**
- **Suborbital Launch Vehicle**
- **Supply of H_2O_2 (max. 97 %)**

Introduction: WEPA-Technologies GmbH

Introduction: WEPA-Technologies GmbH

- **Background**
  - **Founded in 2011 via spin-off (origin: mechanical engineering company)**
- **Company focus**
  - **Engineering-, Automation- and Aerospace-Solutions**
- **Business premises**
  - **700m^2 work shop**
  - **150 m^2 office space**

=> R&D focussed engineering office and manufacturing company

Business Activities

Generell

- <u>**Planning, development and realization of non-standard solutions**</u>
- **Manufacturing of prototypes and small lots (company owned workshop)**
- **Broad range of manufacturing technologies**
  - **CNC-machining**
    - › **Turning (max. 1.4 m diameter x 4 m length)** **(up to 4 axis)**
    - › **Milling (max. 3.0 m x 0.8 m x 0.8 m)** **(up to 5 axis)**
    - › **Metal spinning**
    - › **Wire eroding**
  - **Conventional machining**
    - › **Grinding, welding, sheet metal work**
- **Refences include…**
  - **CASSIDIAN GmbH (AIRBUS DEFENCE AND SPACE): development of solid rocket motor (up to 2 to thrust)**
  - **Dynamit Nobel Defence GmbH**

Business Activities (Products & Services)

Business and development segments

- **Rocket technology (development)**
  - **Propulsion**
    - **Liquid propellant rocket engines (LPRE)**
    - **Turbo pumps for LPRE**
    - **Solid rocket motors (SRM)**
  - **Complete systems**
    - **Suborbital rockets**
    - **(“Micro-Satellite Launch Vehicle”)**

- **Engineering (business)**
  - **Construction and manufacturing of mechanical parts**
- **Automation (business)**
  - **Focus on control retrofits of CNC-machine tools**

solid rocket motor test (thrust: 20 kN)

Micro Satellite Launch Vehicle

Micro Satellite Launch Vehicle: is there a demand ? 1

Today‘s standard launch service for micro satellites:

=> Secondary payload flights !

Characteristics of „secondary payload“ flights

- Launch time and orbit depending on primary payload
- Usually significant lead time (> 1a)
- Additional costs for installation / adaptation of payload
- Significant restrictions concerning nature of payload

Significant percentage of flights are offered by non European agencies:

- Development of an European Micro Launch Vehicle will facilitate independent access to space !

=> We are convinced, there is a significant demand for low cost, <u>primary payload</u> flights ! (at present no availability !)

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General design principles

- Based on proven, historic technologies advanced by modern standard materials and production technologies

  => Avoid modern 'high end materials'

- Preferred use of standard, mass production parts (very few custom tailored parts used)

  - In-house manufacturing of key propulsion components

- Designed to three stages

  => Provides higher margins and enables use of 'low tech' approaches (propulsion, construction materials)

- Commonality approach: maximum use of identical parts in all rocket stages

  => comparable propulsion technology in stage 1 + 2, prefer 'numbering up' / 'clustering' instead of scale up (use turbo pump feed system) !

- Propulsion system of stage 3 is restartable (use pressure feed system)

  => improved orbit insertion capabilities

- Environmentally friendly and easy to handle fuel combination (LOX or H_2O_2 / EtOH)

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Micro Satellite Launch Vehicle – conceptional design 3

General remarks

- Payload requirement: 50 – 100 kg to LEO (Micro Satellites, equipment, etc.)
- Design driven by low cost, not performance !
- Basic structure: 3 stages
- Propellants: LOX ; EtOH (base case, all stages)
- Use of H_2O_2 (85; 95 %) in all stages considered – advantages especially within upper stages:
  - Storability / no evaporative losses during pre-operation time
  - Simplified, non cryogenic feed system (turbo pump resp. pressure feeding)
  - No chill down of system prior to ignition required
  - Reliable, "hypergolic" ignition process
  - Multiple burns possible (=> advantage to achieve precise orbital insertion !)
  - No safety / toxicity issues compared to N_2O_4 / UDMH (standard hypergol !)

  => Reduced system complexity / increased operational reliability !

Boundary conditions of design cases (different oxidizer)

- Outer envelope kept constant
  - Stage 1: d = 1.61 m
  - Stage 2: d = 1.06 m
  - Stage 3: d = 0.72 m

  => total height: 15.2 m

- Propulsion parameter

Stage	Thrust	Pressures			Efficiency	Isp		
						LOx /	H2O2 (85 %)	H2O2 (95 %) /
		p(chamber)	p(nozzle exit)	p(ambient)		EtOH (96%)	EtOH (96%)	EtOH (96%)
[-]	[kN]	[MPa]	[MPa]	[MPa]	[%]	[s]	[s]	[s]
1	4 X 35	5	0,05	0,1	95	255	227	237
2	1 X 35	5	0,005	0,005	95	313	278	292
3	1 X 10	1	0,001	0,001	95	310	278	291

(calculated via RPA-Software)

- ideal rocket equation used to determine final velocity (v_{min} = 7,5 + 2,0 = 9,5 km / s)

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Performance summary

Stage	Propellant combinations (fuel: all stages **EtOH**)			
1	LOX	LOX	LOX	H2O2 85 %
2	LOX	LOX	H2O2 95 %	H2O2 95 %
3	LOX	H2O2 95 %	H2O2 95 %	H2O2 95 %
GLOW [t]	11,0	11,0	11,3	13,7
Payload (LEO) [kg]	**72**	**73**	**72**	**71**
Payload (LEO) [% GLOW]	0,65	0,66	0,64	0,52

outer envelope = const. !
(diameter, height)

H2O2 driven upper stages:

reduced system complexity / increased operational reliability !

=> In terms of payload the use of 95 % H_2O_2 is equivalent to LOX, but comes along with significant advantages !

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Performance summary of selected design cases

outer envelope = const. ! (diameter, height)

Stage	Propellant combinations (fuel: all stages **EtOH**)				
1	LOX	LOX	LOX	H2O2 85 %	H2O2 85 %
2	LOX	H2O2 85 %	**H2O2 95 %**	H2O2 85 %	**H2O2 95 %**
3	LOX	H2O2 85 %	**H2O2 95 %**	H2O2 85 %	**H2O2 95 %**
GLOW [t]	11,0	11,2	11,3	13,7	13,7
Payload (LEO) [kg]	**72**	**51**	**72**	**50**	**71**
Payload (LEO) [%]	0,65	0,46	0,64	0,36	0,52

+ 41 % payload capacity (H_2O_2: 85 => 95 %)

Conclusion

- Increase of payload capacity by ~ 41 % after increasing H_2O_2 concentration to 95 %
- Only 95 % H_2O_2 results in payload capacity comparable to LOX (outer envelope = constant) !

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Performance summary of selected design cases

outer envelope = const. !
(diameter, height)

Stage	Propellant combinations (fuel: all stages **EtOH**)			
1	LOX	LOX	LOX	H2O2 85 %
2	LOX	LOX	H2O2 95 %	H2O2 95 %
3	LOX	H2O2 95 %	H2O2 95 %	H2O2 95 %
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Payload (LEO) [kg]	**72**	**73**	**72**	**71**
Payload (LEO) [% GLOW]	0,65	0,66	0,64	0,52

H2O2 driven upper stages:
reduced system complexity / increased operational reliability !

Conclusion

- Projected payload can be realized by different oxidizer / stage combinations
- In terms of payload the use of 95 % H_2O_2 is equivalent to LOX, but comes along with significant advantages !
- Most suitable propellant system depending on specific boundary conditions (availability of propellants, experience, storability issues, preference of team…)

  => No final, general recommendation can be given

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Low cost propulsion system considered (one) key component to realize low cost Micro Satellite Launches !

How to achieve low cost propulsion ?

- Simplified design of rocket engines and turbo pumps
- Low-level operational parameter (chamber pressure, temperature)
- Use of low cost materials and manufacturing technologies
- Unification of propulsion system design for first and second stages via clustering (identical propellants assumed !)
- Prefer numbering-up instead of scale-up
- Environmentally benign and easy to handle propellant components (LOX resp. H_2O_2, EtOH)

Additional use of MSLV propulsion hardware ?
Suborbital Launch Vehicle !

Suborbital Launch Vehicle – development approach 1

Micro Satellite Launch Vehicle (MSLV): incremental development process

- 2nd stage: used for development / validation of key technology fields !

Combination of 2nd stage MSLV and payload section of <u>existing, commercial sounding rockets</u> feasible ?

=> independence of surplus military booster

=> Qualified equipment could be re-used (data acquisition + downlink, power supply, telemetry…)

=> eventually significant increase of payload / flight apex / zero-g time possible (depending on present configuration !)

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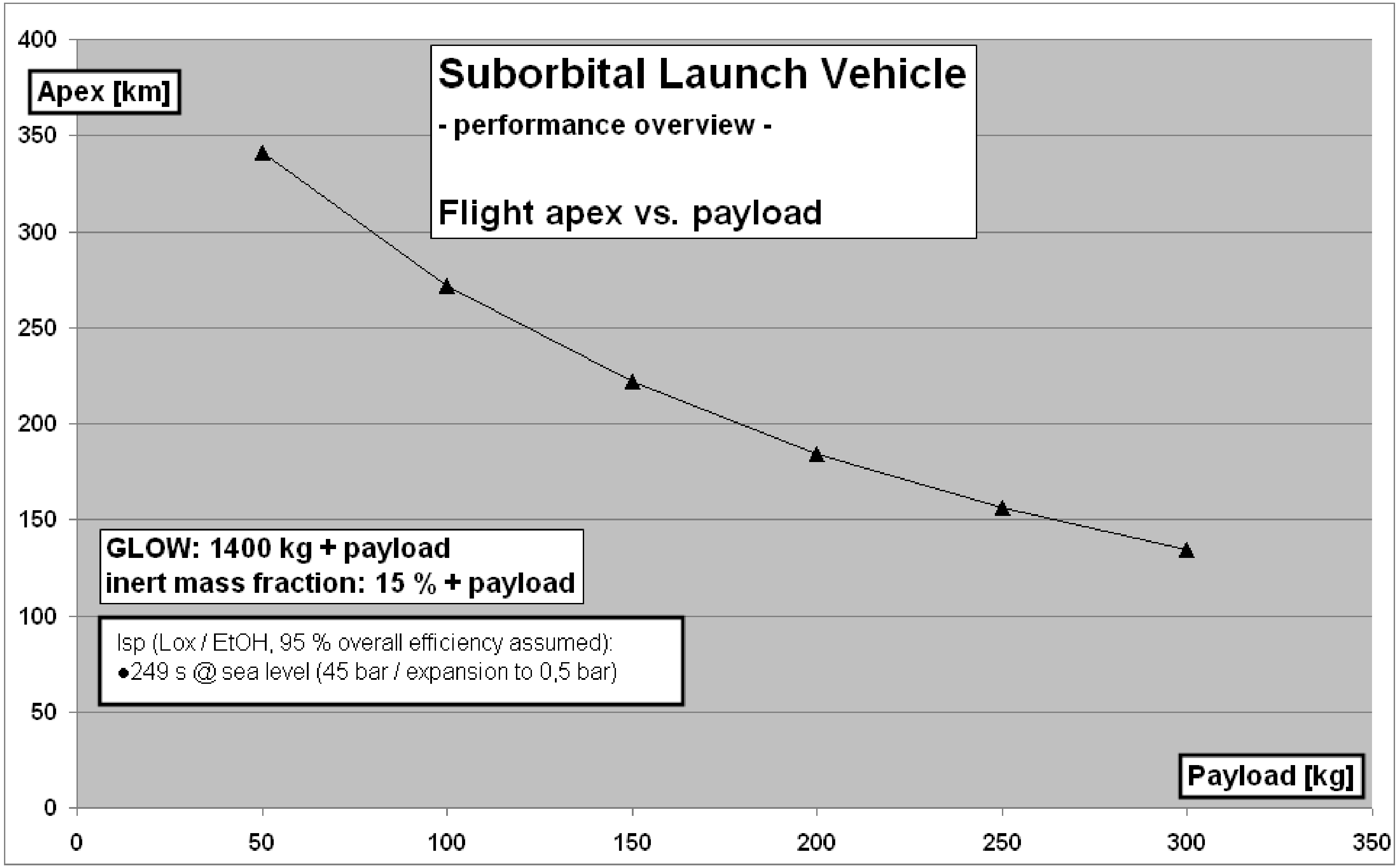
Suborbital Launch Vehicle – flight parameter

- Wide range of flight parameter realizable: first simulation results



Next steps:

discuss options with present users of commercial sounding rockets

Current development: Turbo Pump Unit

Current Development: Turbo Pump Unit – overview 1

- Goal: minimize engineering, testing + manufacturing effort by low level operational parameter
  - Exit pressure: max. 75 bar
  - Max. 30,000 RPM; single shaft design
  - Open gas generator cycle (LOX / EtOH or H_2O_2:)
- Propellant systems: LOX / EtOH (HTP / EtOH)
- Mass flow rate: ~ 14 kg/s LOX / EtOH (35 kN engine)
- Turbine
  - Single axial stage, impulse type
  - Inlet temperature: < 850 K
- Pump
  - Single radial stage
- Weight: max.35 kg (incl. gas generator + control unit)
- Arrangement: turbine – EtOH – oxidizer

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Current Development: Turbo Pump Unit – overview

- **Cooperation partner**
  - Technical University of Dresden (present)
    (Institute for Aerospace Engineering / Chair for Space Systems: Prof. Tajmar / Dr. Przybilski))
  - University of Applied Sciences Cologne (2012)
    (Institute for Product Development and Construction Technology: Prof. Mueller)

TU-DD 2014
(H. Wolter)

- **Status**
  - Detailed construction in progress (completion: September 2014)
  - Manufacturing: August – November 2014 (mainly conducted in workshop of WEPA-Technologies)
  - Start of prototype qualification: December 2014

=> general commercialisation of turbo pump units intended

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Current Development: Liquid Propellant Engines

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Overview

- **Goal: construction of low cost engines**

  => Significant reduction of development and production costs required

- **Approach: improve designs based on proven technologies (USA / USSR 1950 – 1970)**

- **Use of 'green propellants' (LOX / EtOH, H_2O_2 / EtOH)**

  => No significant environmental issues (test & launch area)

- **Thrust range: 10 – 60 kN**
  - **Increase to level of 100 – 200 kN mid term goal**

- **Potential applications**
  - Sounding rockets
  - Launch vehicles
  - Defence (Air, Ground, Naval)

Current development (technology demonstrator)

- **Operating parameter**
  - Thrust
    - 35 kN
  - Chamber pressure:
    - 5 MPa
  - Nozzle exit pressure: (adapted to working altitude)
    - 0.05 MPa / 0.005 MPa
  - Propellants:
    - LOX / EtOH
    - H_2O_2 / EtOH
- Construction overview
  - Injector: swirl type
  - Regenerative cooling: LOX / EtOH, H_2O_2 / EtOH
  - Thrust chamber: use series production enabling technologies (welding, brazing)

=> commercialisation of LPRE intended

WEPA Technologies

Supply of H_2O_2 (c > 88 %)

Technologies

Supply of H_2O_2 (c > 88 - 97 %)

- **Motivation (see section "Micro Satellite Launch Vehicle")**
  - Use of H_2O_2 in upper stages: likely to significantly increase operational reliability
  - Increase of H_2O_2 concentration (85 => 95 %): identical payload compared to LOX (outer envelope kept constant !)

- **Commercial Supply situation (present)**
  - Very limited availability at c > 88 %
  - Transport via public ground prohibited by law

    => on site production in specialized plants required !
  - Small production plants cannot be rented, only bought (> 1,8 Mio EUR, ~ 1 kg H_2O_2 / h)

  => Not very attractive situation for developing very high concentration, H_2O_2 based propulsion processes….

WEPA Technologies

Supply of H_2O_2 (c : 88 - 97 %)

- **Present activities at WEPA-Technologies**
  - Development of very safe, automated, low temperature concentration technologies (max. 97 %) (cooperation with external partner)
    - Mobile production plant ("car trailer sized")
    - About 10 kg / h production capacity (starting material: 60 – 85 % H_2O_2)
    - Production has to be conducted at customers site (400 V / 16 A; water required)
    - World wide operation by WEPA personal possible
      (precondition: compliance with EC export rules)
- **Status and timeline (WEPA process)**
  - At present: Lab scale validation (non mobile plant setup)
  - Timeline for completion of mobile plant does depend on market demand / customer requests
- **Applications**
  - Booster and upper stages (launch vehicles or sounding rockets: LPRE or hybrid type)
  - Station keeping
  - Gas generators
  - Defense (Air, Land, Naval)

=> general commercialisation of H_2O_2 supply intended (90 – 97 %)
=> customer requests welcome !

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Summary

- **Present development at WEPA-Technologies GmbH**
  - **Liquid propellant rocket engines incl. turbo pump units**
    - **Present: 35 kN LPRE technology demonstrator (LOX/EtOH; H_2O_2 / EtOH + TPU)**
    - **Possible application: booster for sounding rockets**
      - **Better variability of payload size / max. altitude**
      - **Significantly lower safety issues due to lack of solid propellants !**
  - **H_2O_2**
    - **Development of mobile concentration unit**
      - **Production of 97% on customers site**
      - **Significant advantages in upper stage use (operational reliability)**
- **Preliminary design of Micro Satellite Launch Vehicle**
  - **70 kg (LEO) (LOX / EtOH; H_2O_2 / EtOH)**
  - **3 stage design, 15.3 m total height, 11 – 13.7 to GLOW**
  - **Use in 95 % concentration yields comparable performance to LOX (system view)**

=> customer requests welcome !

Thank you for your attention !

WEPA Technologies

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