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

Space Propulsion 2014

Cologne, 2014-05-20

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WEPA-Technologies GmbH

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

Business Activities (Manufacturing) 1

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) 2

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 %
GLOW [t]	11,0	11,0	11,3	13,7
Payload (LEO) [kg]	**72**	**73**	**72**	**71**
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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

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 !

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Suborbital Launch Vehicle – development approach

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 existing, commercial sounding rockets 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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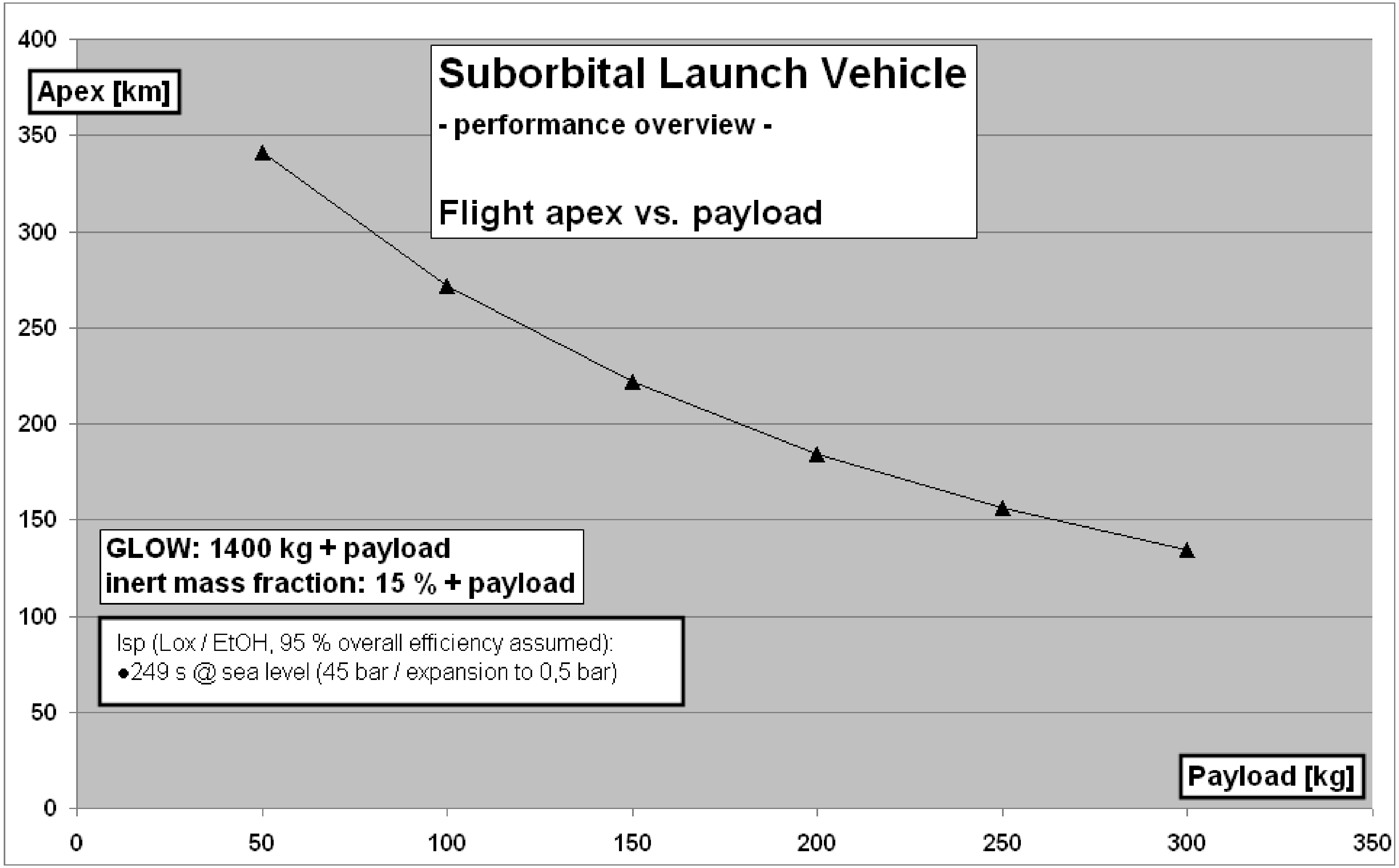
Suborbital Launch Vehicle – flight parameter

- 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

Current Development: Liquid Propellant Engines

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

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Supply of H_2O_2 (c > 88 %)

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Supply of H_2O_2 (c > 88 - 97 %) 1

- **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

    => <u>on site production in specialized plants required !</u>
  - 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….

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 !

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