Development of Low Cost Propulsion Systems for Launch- and In Space Applications

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Dr.-Ing. Peter H. Weuta
Dipl.-Ing. Neil Jaschinski

WEPA-Technologies GmbH (Germany)

Introduction: WEPA-Technologies GmbH

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

=> R&D focussed engineering office and manufacturing company

Business Activities

Business Activities (Manufacturing) 1

Generell

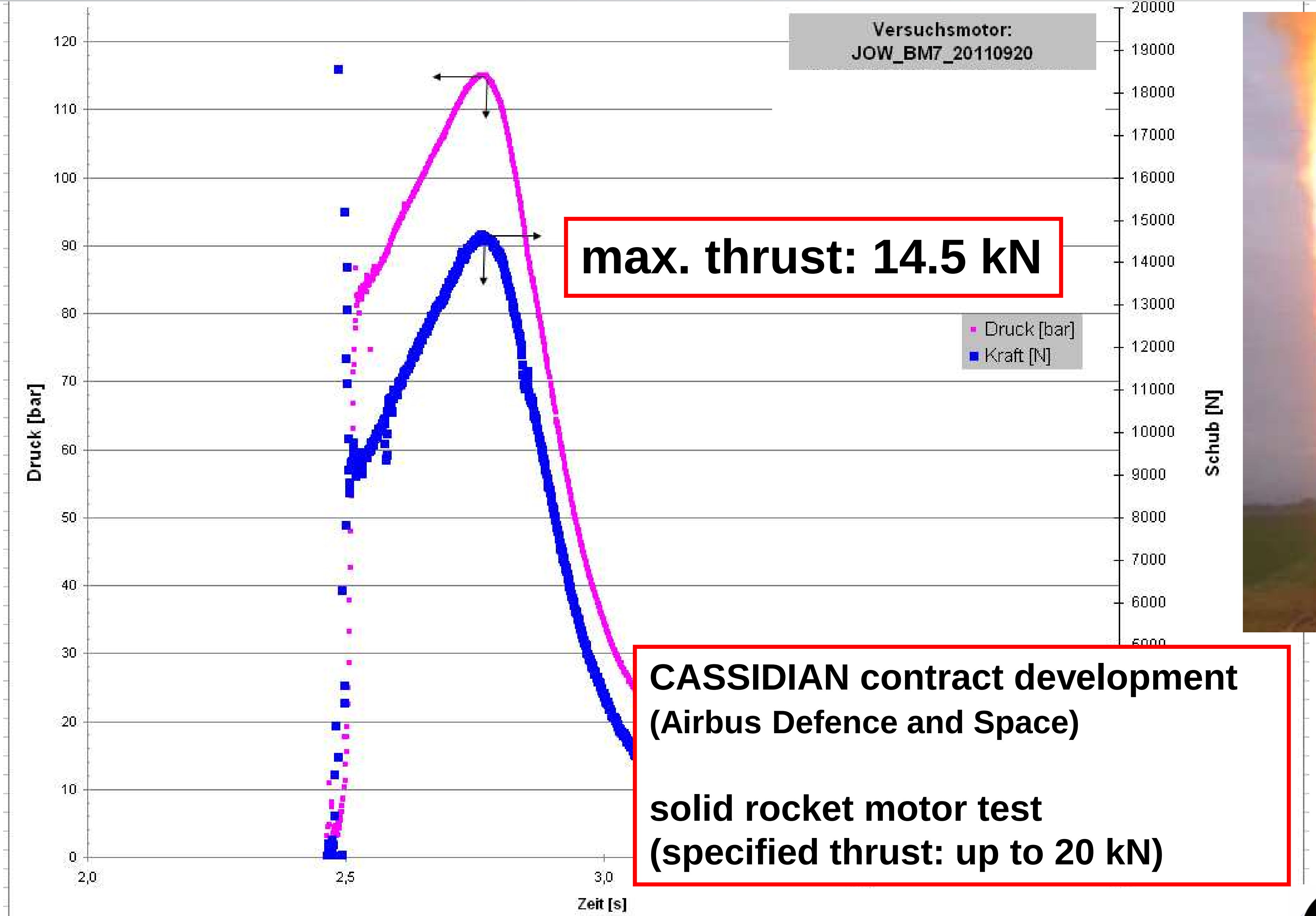
- **Planning, development and realization of non-standard solutions**
- **Manufacturing of prototypes and small lots (company owned workshop)**
- **Broad range of manufacturing technologies**
  - **CNC-machining**
    - › **Turning (max. 1.4 m diameter x 4 m length) (up to 4 axis)**
    - › **Milling (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**
- **Public references include…**
  - **CASSIDIAN GmbH (Airbus Defence & Space)**
  - **Dynamit Nobel Defence GmbH**
  - **EU-customer (H_2O_2 - concentration plant)**

Business Activities (Rocket Technology) 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 sounding rockets (propulsion unit)**
    - **H_2O_2 - concentration plants (max. 98 %)**
- **Engineering (business)**
  - **Construction and manufacturing of mechanical parts**
- **Automation (business)**
  - **Focus on control retrofits of CNC-machine tools**

CASSIDIAN contract development
(Airbus Defence & Space)
solid rocket motor test (thrust: 20 kN)



max. thrust: 14.5 kN

CASSIDIAN contract development
(Airbus Defence and Space)

solid rocket motor test
(specified thrust: up to 20 kN)

http://www.wepa-technologies.de/references/cassidian-eads/

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General Development Strategy: Rocket Technology

Present Development Strategy 1

Key development fields

Turbo Pump

35 kN LPRE

LOX / Kerosene (EtOH)
(p_c: 50 bar / I_{sp}: 260 (250s) @SL)

H_2O_2 – concentration Plants (max. 98 %)

H_2O_2 (95 %) / Kerosene
- non cryogenic stage
- simplified design
- high system reliability
(relevant in upper stages !)

Potential customer applications

Micro Satellite Launch Vehicle; f. ex.
- 50 – 100 kg LEO
- 9 – 10 to GLOW
- 3 stage design

⇒ stage 1: 4 x 35 kN
⇒ stage 2: 1 x 35 kN

Sounding Rockets

Present Development Strategy

Low cost propulsion system considered (one) key component to realize low cost launch- and in space applications !

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, Kerosene, LCH_4)
  - Avoid NO_2 / N_2O_4 and hydrazine !

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Development of 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 / Europe 1960 – 1980)**

- **Use of 'green propellants'**
  - **Oxidizers: LOX / H_2O_2**
  - **Fuels: EtOH / Kerosene / LCH_4 / (LH_2)**

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

- **Present development: 35 kN technology demonstrator**
  - Chamber pressure: 5 MPa
  - Exit pressure: 0,5 MPa
  - Regenerative cooling

- **Increase to 100 – 200 kN thrust mid term goal (depending on market requirements)**

=> commercialisation of LPRE intended

Current development (technology demonstrator)

- **Operating parameter**
  - Thrust
    - 35 kN
  - Chamber pressure:
    - 5 MPa
  - Nozzle exit pressure:
    - 0.05 MPa (=> 1. stage engine)
  - Propellants:
    - LOX / EtOH
    - H_2O_2 / EtOH
- Construction overview
  - Regenerative cooling: LOX / EtOH, H_2O_2 / EtOH
  - Thrust chamber: use series production enabling technologies (welding)
- Injector:
  - coaxial type (LOX and H_2O_2-based propellants)

Current development (technology demonstrator): specifics of H_2O_2-based propulsion systems

- Use of highly stabilized H_2O_2 preferred
  - Significantly increased safety level during H_2O_2 production, storage and use
  - ⇒ Lower cost systems !
- Injector
  - Coaxial type
  - Catalytic pre-decomposition of H_2O_2 not mandatory
    - Direct liquid injection preferred
      - › No catalyst required !
    - Hypergolic ignition by initial injection of organic or inorganic starters !
- Thrust chamber
  - Significantly lower combustion temperature compared to LOX systems
    - Facilitated reusability of propulsion systems ! (space planes / space tourism)
  - Regenerative cooling by H_2O_2

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Current development (technology demonstrator):
specifics of H_2O_2-based propulsion systems

- 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 !

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Turbo Pump Units

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 + catalyst)

- Propellant systems: LOX / EtOH (H_2O_2 / EtOH)

- Mass flow rate: ~ 14 – 14.5 kg/s (35 kN engine)

- Weight: max.35 kg (incl. gas generator + control unit)

- Arrangement: turbine – EtOH – oxidizer

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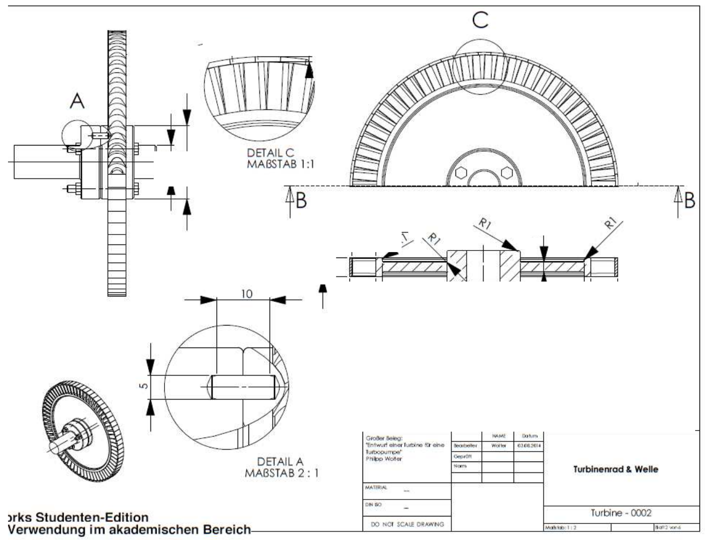
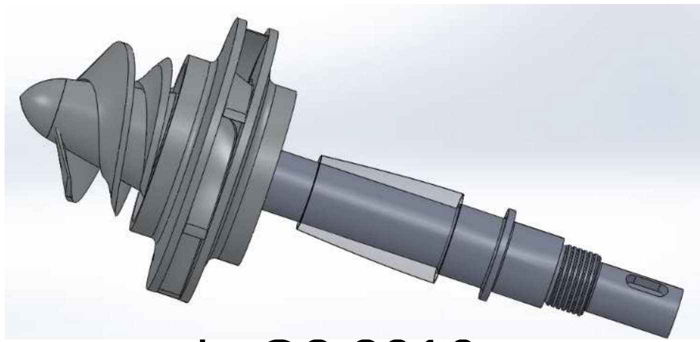
Current Development: Turbo Pump Unit – overview 2



- Turbine
  - single or double axial stage, impulse type
  - partial admission of drive gas
  - inlet temperature: < 850 K
- Pump
  - single radial stage
- Seals
  - dynamic type
- Weight: max.35 kg (incl. gas generator + control unit)
- Arrangement: turbine – fuel – oxidizer



- <u>Status</u>
  - First hot firing test of LPRE and TPU to commence in Q3 2016

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H_2O_2-Concentration Technology

Supply of H_2O_2 (c > 88 - 98 %)

- **Motivation**
  - Due to non-cryogenic nature of H_2O_2 overall system architecture is significantly reduced (no isolation required, no formation of ice, less complicated TPU)
  - H_2O_2-based propulsion systems show very high operational reliability
  - Very high strength H_2O_2 required for high performance propulsion systems
  - Increase of H_2O_2 concentration (85 => 95 %): identical payload capacity compared to LOX (outer envelope kept constant !)

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Supply of H_2O_2 (c > 88 - 98 %)

- **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 a very attractive situation for developing / using H_2O_2 - based propulsion processes….

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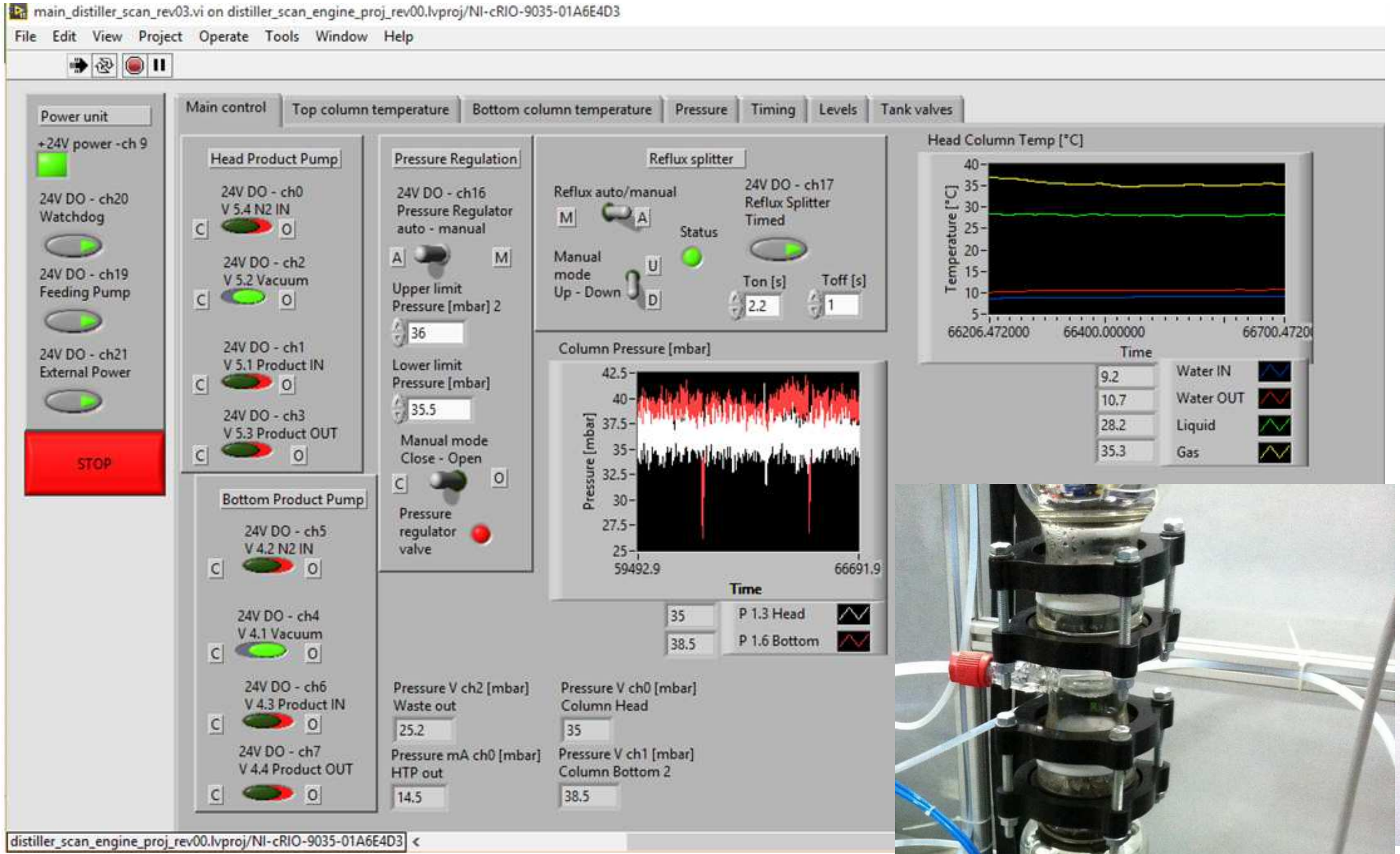
Supply of H_2O_2 (c > 88 - 98 %)

- H_2O_2 concentration plant developed by WEPA-Technologies (current EU-customer)
  - Capacity: up to ~ 50 kg / d (90 %)
  - Feed: 50 % - 70 % H_2O_2
  - Fully automatic, 24 / 7 operability
- Working packages supplied by WEPA-Technologies
  - Conceptional process design incl. safety concept
  - Detail Engineering (process-, control- and electrical diagrams)
  - Equipment purchase
  - Erection and commissioning
  - Trouble shooting / maintenance

Reference plant open to customer visits (commissioning complete: 10/2015)

- Very safe production process up to 98 % concentration under development (10 kg / h): fully mobile set-up in 20 – 40 ft container

Supply of H_2O_2 (90 %) : Reference Plant



=> general commercialisation of H_2O_2 supply intended (90 – 98 %)
=> customer requests welcome !

Control by PLC:
LabVIEW RT
(alternative: TWINCAT)

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Summary

Summary - Present development at WEPA-Technologies

- **Liquid propellant rocket engines incl. turbo pump units**
  - **Present: 35 kN LPRE technology demonstrator (LOX/EtOH; H_2O_2 / EtOH + TPU)**
    - **Use of LOX / Kerosene and LCH_4 projected !**
  - **Low cost focus**
  - **Possible application: booster for micro satellite launch vehicles or sounding rockets**
  - **First hot firing test of LPRE and TPU to commence in late Summer 2016**
- **H_2O_2**
  - **H_2O_2 significantly facilitates development and reliable operation of propulsion systems – however: very difficult supply situation at concentration > 88 % (sometimes even valid below 88 % !)**
  - **WEPA solution: development of mobile concentration unit**
    - **Key features:**
      - **Safe and fully automatic, 24 / 7 operability**
    - **Production technology of 90 % H_2O_2 fully developed (reference plant available : ~ 50 kg / day capacity)**
    - **Process to yield 98% H_2O_2 available by late 2016**

=> customer requests welcome !

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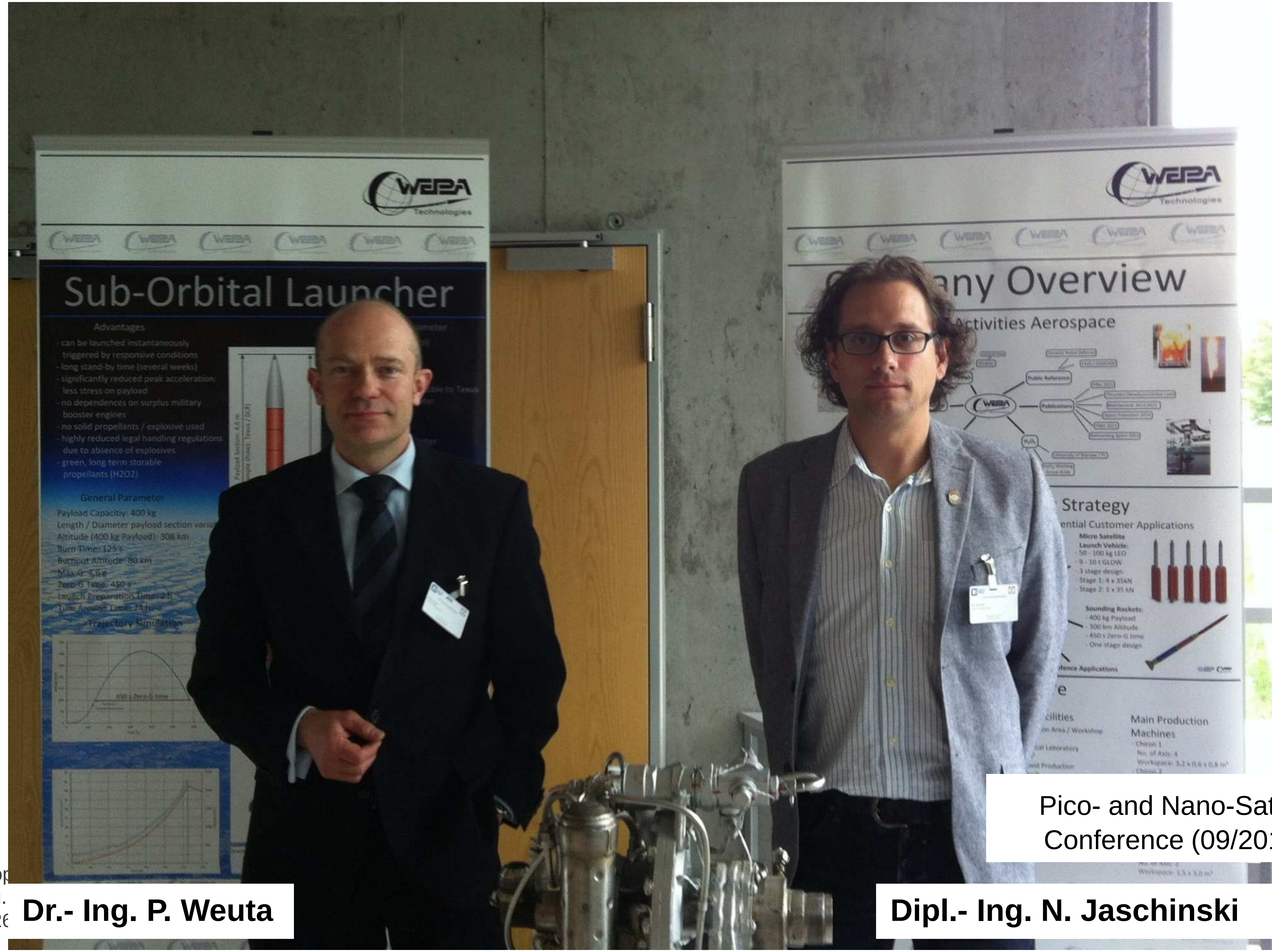
Thank you for your attention !



Pico- and Nano-Satellite Conference (09/2015)

Dr.- Ing. P. Weuta

Dipl.- Ing. N. Jaschinski

peter.weuta@wepa-technologies.de
www.wepa-technologies.de

Back-Up

Application of Propulsion Technology: Conceptional Design of Sounding Rocket „SILBERPFEIL“ („Silver Arrow“)

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Central Design Decision:
Liquid- or Solid Propellant Rocket Engines ? 1

By far most sounding rockets use Solid Rocket Motor propulsion systems

- Surplus military motors
  - ready availability not always given
- Very high acceleration of vehicle
  - significant stress on payload
- Thrust / time profile and total impulse cannot be modified
- Safety and cost issues using solid propellants
  - regulations for “explosives” becoming even more stringent:
    - transport
    - storage
    - handling / on site integration

Conclusion: Solid Rocket Motors show significant disadvantages for frequent low cost launches !

Central Design Decision:
Liquid- or Solid Propellant Rocket Engines ? 2

Advantages of Liquid Propellant Rocket Engines

- Completely safe handling of rocket during payload integration, handling and transport (=> fuel tanks empty)
  - no stringent safety regulations to be followed
- Low peak acceleration possible to realize
  - low stress on payload
- Launch readiness can be kept up for many weeks: responsive, very low lead time launch possible (while using storable, H_2O_2 oxidizer)
- Environmentally friendly ("green") propellants (while using H_2O_2 or O_2 oxidizer and Kerosene fuel)

Conclusion:

Liquid propellant rocket engines show significant advantages for frequent launches …but have to be made low-priced !

Central Design Goal: Low Cost !

Low cost characteristics of sounding rockets can be achieved by multiple, parallel approaches (focus: propulsion system):

- Significantly reduced safety regulations due to avoidance of explosives (solid propellants)
- Simplified design of propulsion system (rocket engine and turbo pumps)
- Low level operational parameters (chamber pressure)
- Environmentally benign and easy to handle propellant components (H_2O_2 / Kerosene)
- Simple tank structures / no thermal isolation; common bulkhead
- Low-cost materials and manufacturing technologies
  - avoid typical aerospace grade materials and manufacturing processes
- Simple guidance systems / thrust vector control for ballistic flight required
- Goal: 1900 – 3800 EUR / kg @ 400 kg (300 km) payload (0,75 – 1,5 Mio EUR)
  - Depending on flight rate and depreciation of development costs
  - Ground support not included

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Preliminary Design of Sounding Rocket: Definition of Payload Section

- Payload section is very specific to mission requirements
  - Can be adapted to customers needs: length, diameter, total mass
- Choose representative (commercial) payload size: TEXUS module (DLR, ~ 400 kg)
  - Advantages: qualified equipment could be re-used (data acquisition + downlink, power supply, telemetry, recovery systems…)
- Use 35 kN technology demonstrator engine
  - Thrust / time profile could be adapted to mission’s needs

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TEXUS: SRM vs. LPRE-Propulsion? Different Concepts

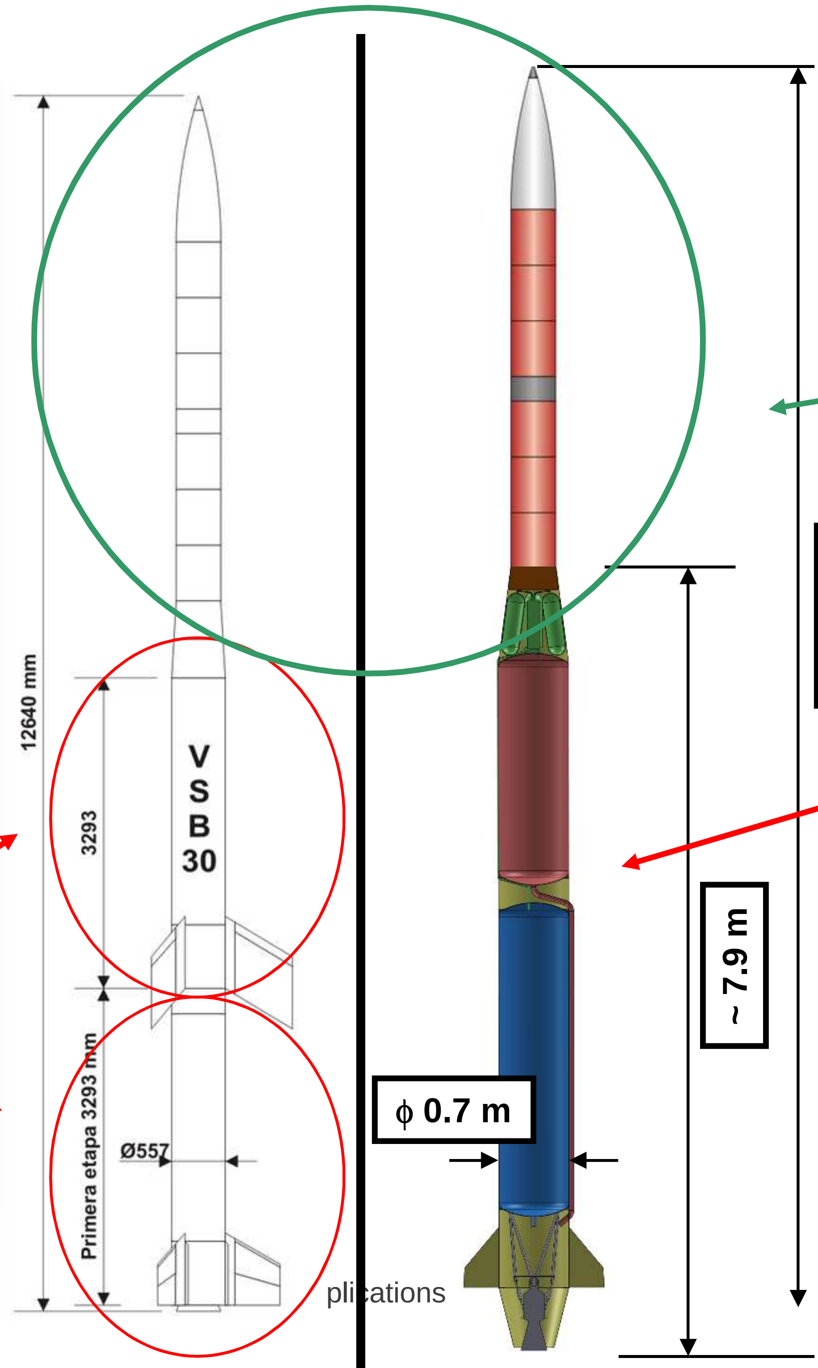
TEXUS
Sounding Rocket

COHETE
VSB-30

DLR /

Características principales
Masa total 2579 kg
Masa de carga útil 400 kg
Apogeo estimado 270 km

Solid Rocket Motor(2)



alternative concept:
WEPA / TU-Dresden
(PL: 400 kg, h_{max}: ~ 300 km)

Identical Payload and Recovery Module

LPRE-Booster: 35 kN thrust
(H_2O_2 / Kerosene)
35 kN @ SL

credit: H. Voigt (2015)

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Summary of results: TEXUS Module via LPRE booster

Comparison of Main Parameters:			
Payload: TEXUS-module			
	VSB-30 base case	**WEPA / TU-DD concept**	
Overall System			
payload / communication / recovery	DLR-Standard	DLR-Standard	
max. height of flight	~ 270	~ 300	[km]
GLOW	2600	2790	[kg]
max. diameter	0,57	0,7	[m]
total length	12,6	13,2	[m]
Payload Module incl. Recovery			
length	4,5 - 5,5	4,5 - 5,5	[m]
diameter	0,44	0,44	[m]
mass	max. 400	max. 400	[kg]
Propulsion System			
number of stages	2	1	[-]
propellants	solid	liquid	[-]
propallant mass	~ 1575	2050	[kg]
max. accelaration	~ 12	4,65	[g]
burn time	31 (11 + 20)	125	[s]

Conclusion:

- Identical max. height (300 km) and payload capacity (400 kg)
- Significantly reduced maximum acceleration => lower stress on payload (4.7 g vs. 12 g)
- Comparable GLOW and outer envelope of complete system
- Reduced safety requirements: no danger during handling, transport, storage
- (Reliable availability of propulsion modules)

credit: H. Voigt (2015)

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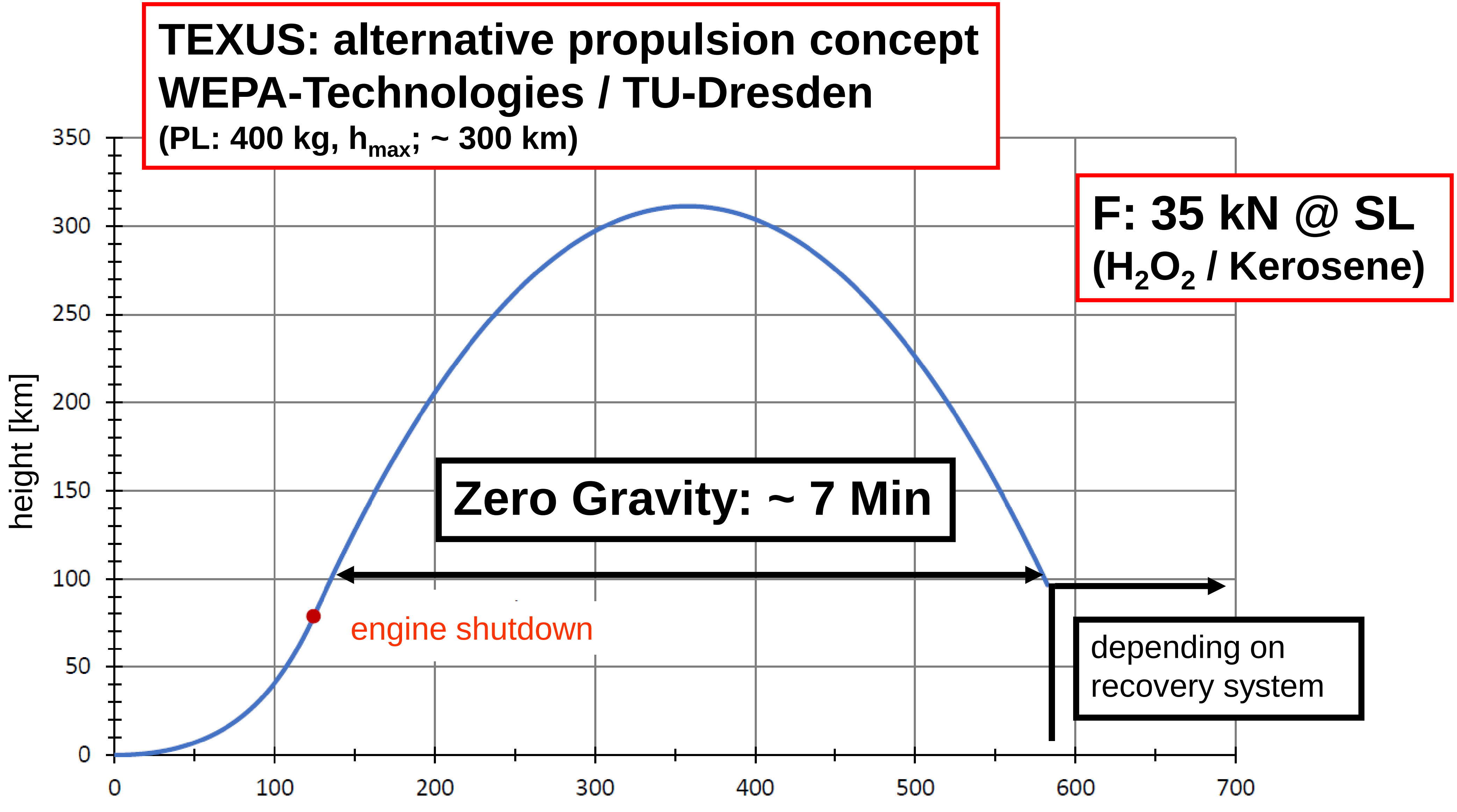
TEXUS Module via LPRE Booster: Simulated Trajectory 1



credit: H. Voigt (2015)

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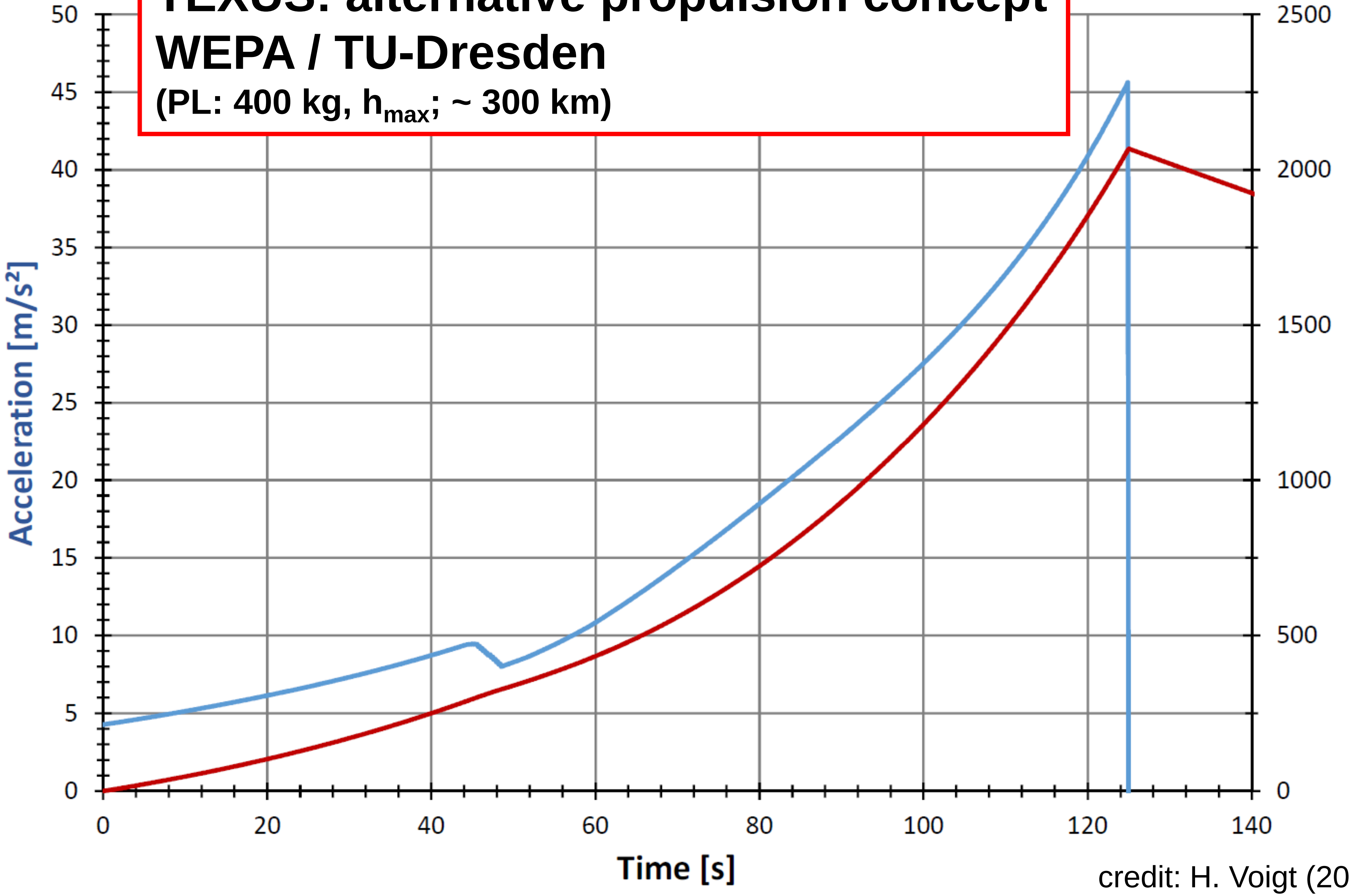
TEXUS Module via LPRE Booster: Simulated Trajectory 2

TEXUS: alternative propulsion concept
WEPA / TU-Dresden
(PL: 400 kg, h_{max}: ~ 300 km)



credit: H. Voigt (2015)

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Summary

- **Basic design parameter of a LPRE-propelled sounding rocket ("SILBERPFEIL") were described**
  - **Due to non-cryogenic nature of H_2O_2 overall system architecture is significantly reduced**
- **Possible applications of SILBERPFEIL**
  - **Zero-g experiments**
  - **Re-entry research**
- **TEXUS payload module (400 kg) has been chosen for reference**
  - **300 km height / ~ 7 min zero-g time**
  - **Other geometries / masses of payload section can be considered**
- **WEPA-Technologies is developing key propulsion-technologies (LPRE resp. turbo pumps) and H_2O_2 - concentration plants independent of the realization of sounding rocket projects**
- **To initiate development of the payload section and complete sounding rocket WEPA-Technologies is open to cooperations**

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