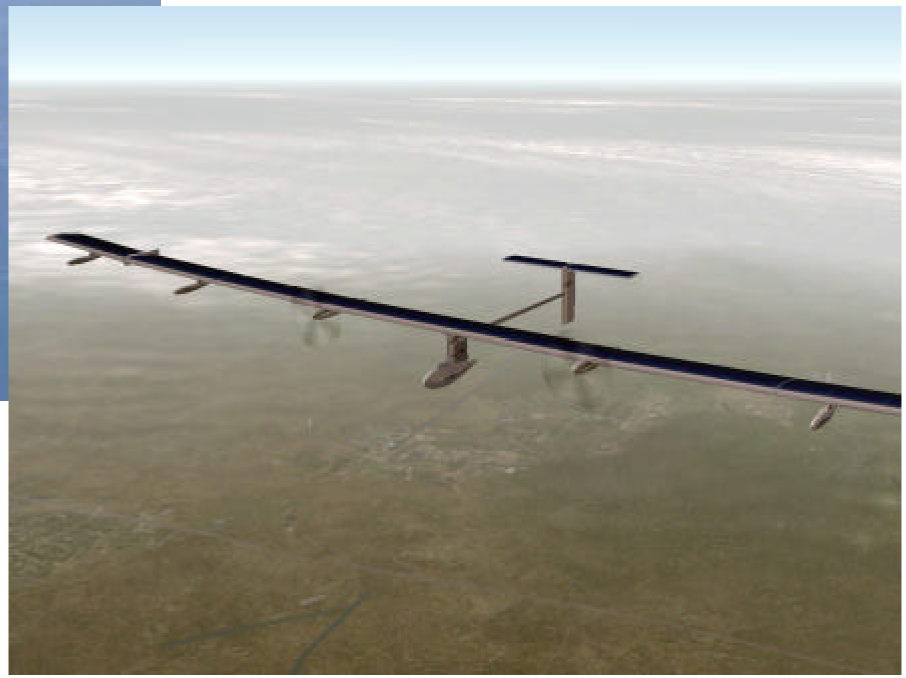
Solar Powered Aircraft

The True All Electric Aircraft

AROUND THE WORLD
WITH A SOLAR AIRPLANE

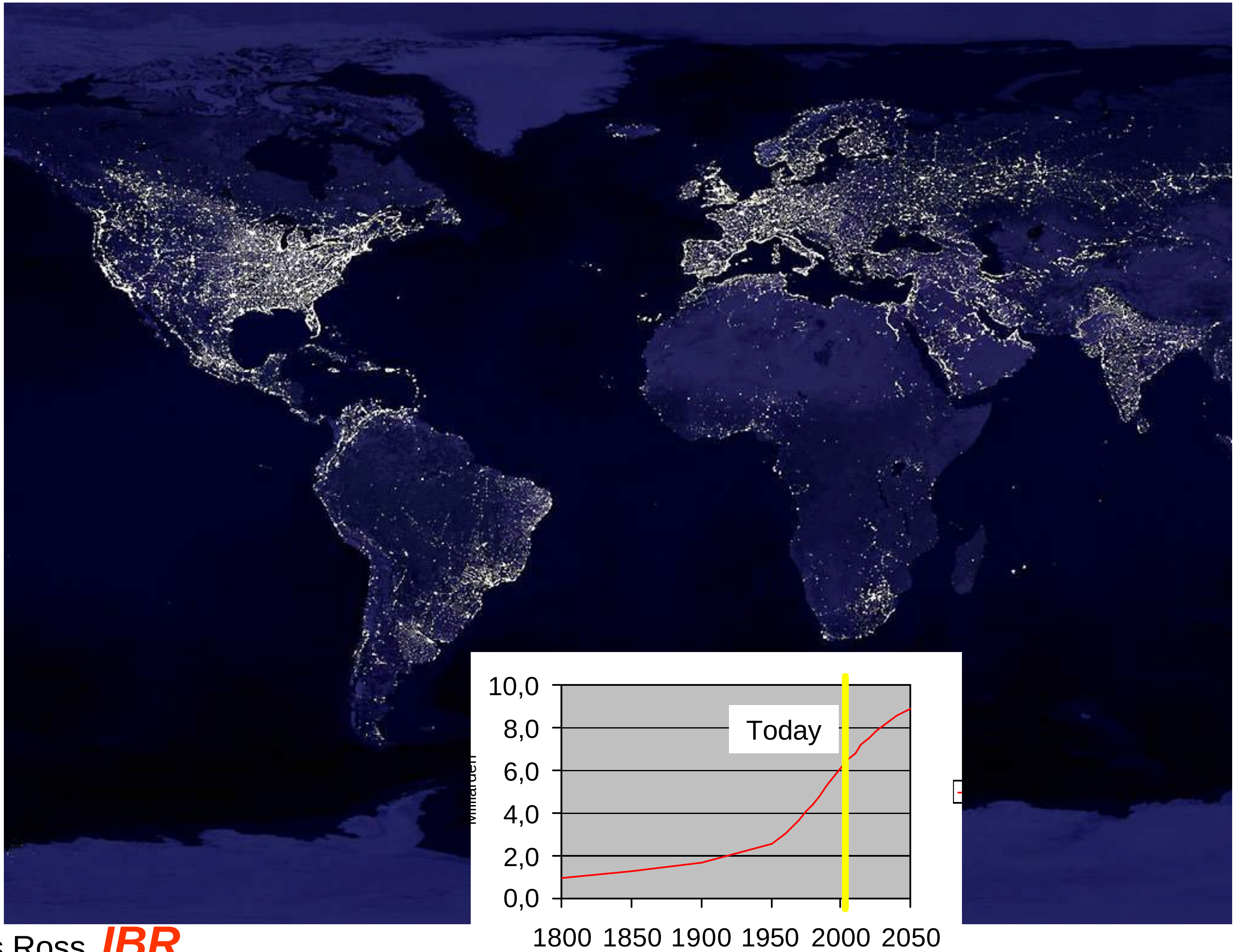


Fly aroung the World with a Solar Powered Aircraft

1. **Solar Power, Basics**
2. Flying Power, Basics
3. Solar Powered AC History
4. Technology Status
5. Manned Solar Powered AC, Solarimpulse
6. Summary

Earth Population:
More than 6 Billion in 2006

AROUND THE WORLD
WITH A SOLAR AIRPLANE



Solar Cells on Roof‘s

„Renewable“ Energy: A Requirement for Mankind

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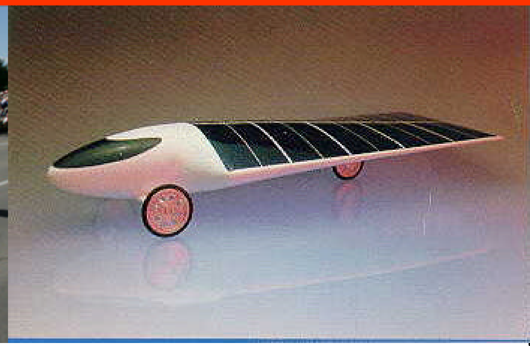
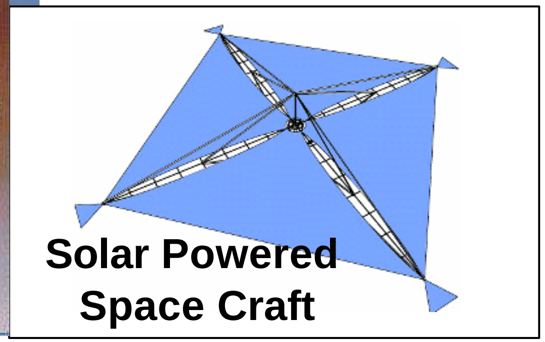
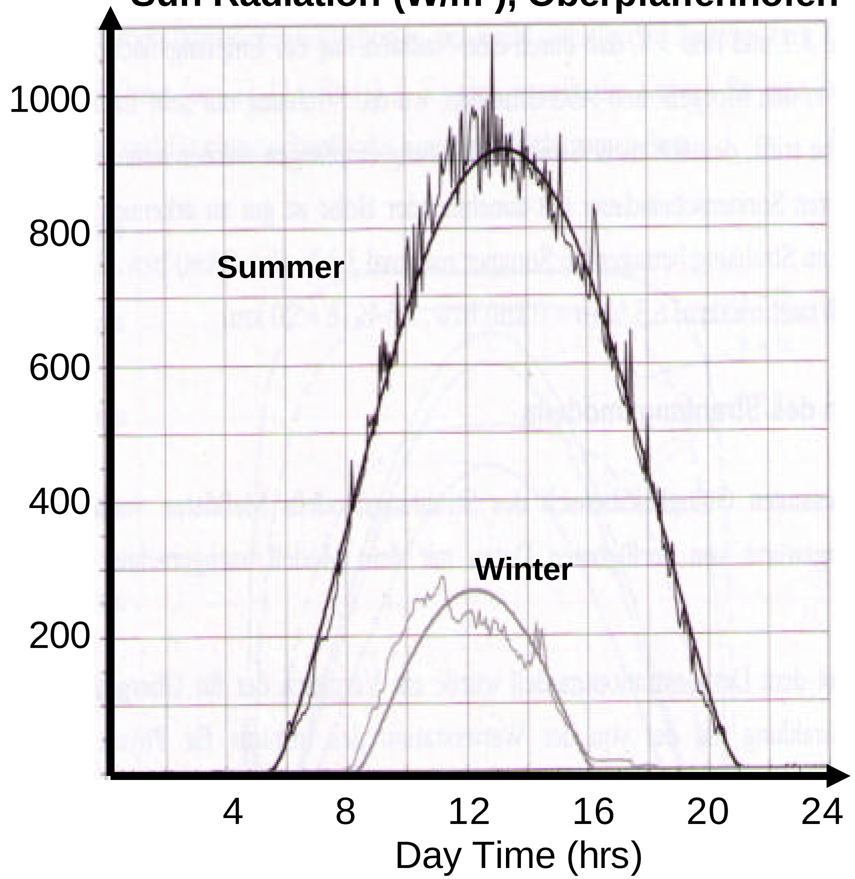
WITH A SOLAR AIRPLANE

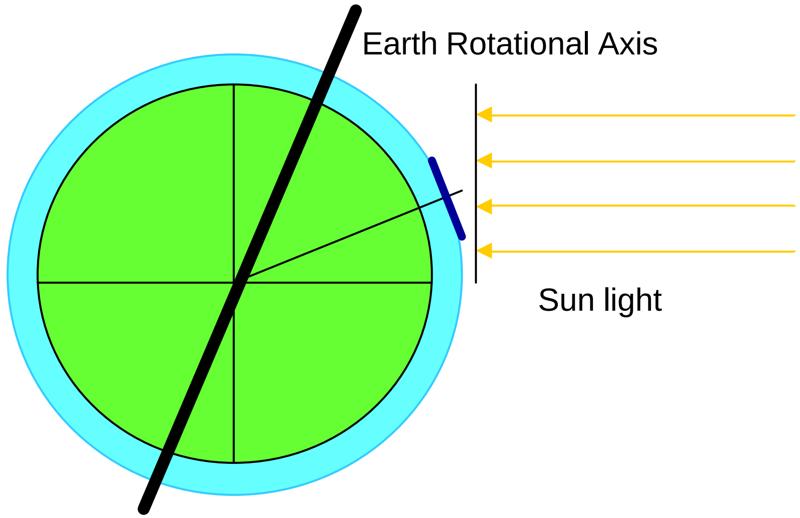




Primary Energy Collection Parameters

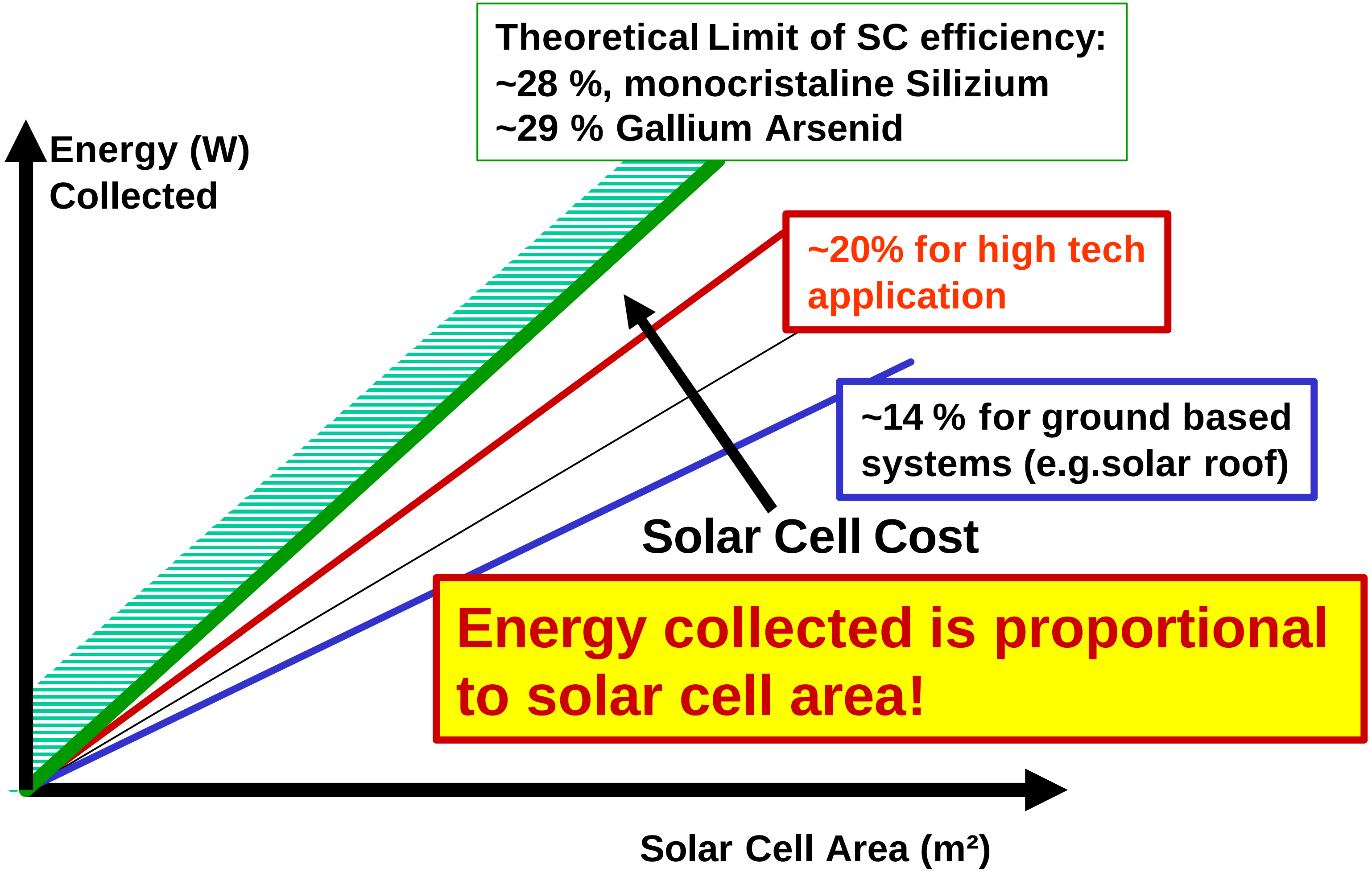


Source: B.Keidel Dissertation



Lattitude,
Time of the year,
Time of the day,
Altitude (Clouds, humidity),
Cell Temperature
Cell Orientation

Solar Energy Collection



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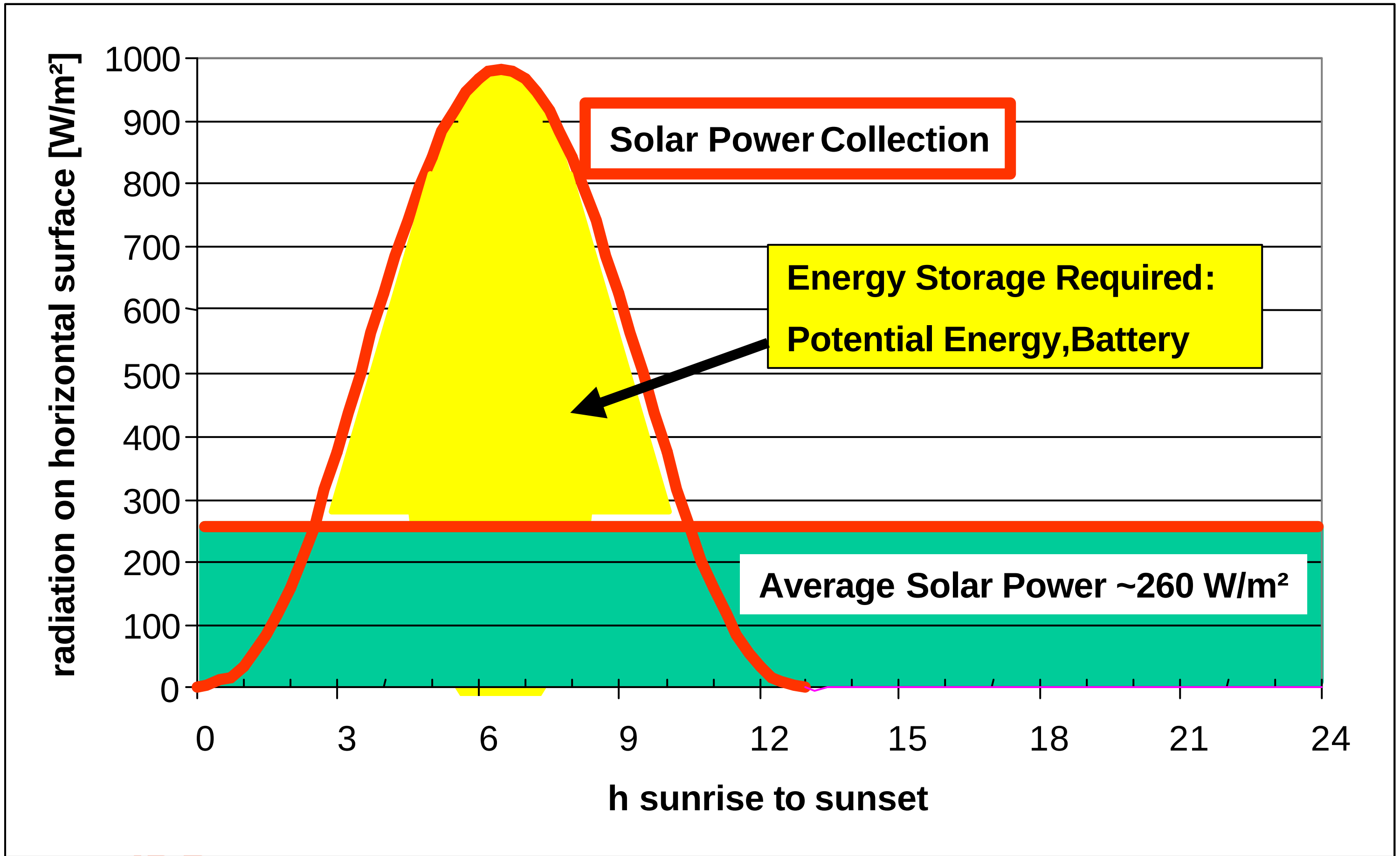
Available Solar Power

Solar constant 1300W/m² extraterrestrial
At flight altitudes approx. 1000W/m² noon peak



Wing Loading and Power Loading For Horizontal Flight

$$Power = Drag * Velocity \longrightarrow P = D * V$$

$$\ldots\ldots\ldots Drag \longrightarrow D = CD * \frac{r}{2} * V \wedge 2 * S$$

$$\ldots\ldots\ldots Velocity \longrightarrow V = \sqrt[2]{\frac{2}{r} * \frac{W}{S} * \frac{1}{CL}}$$

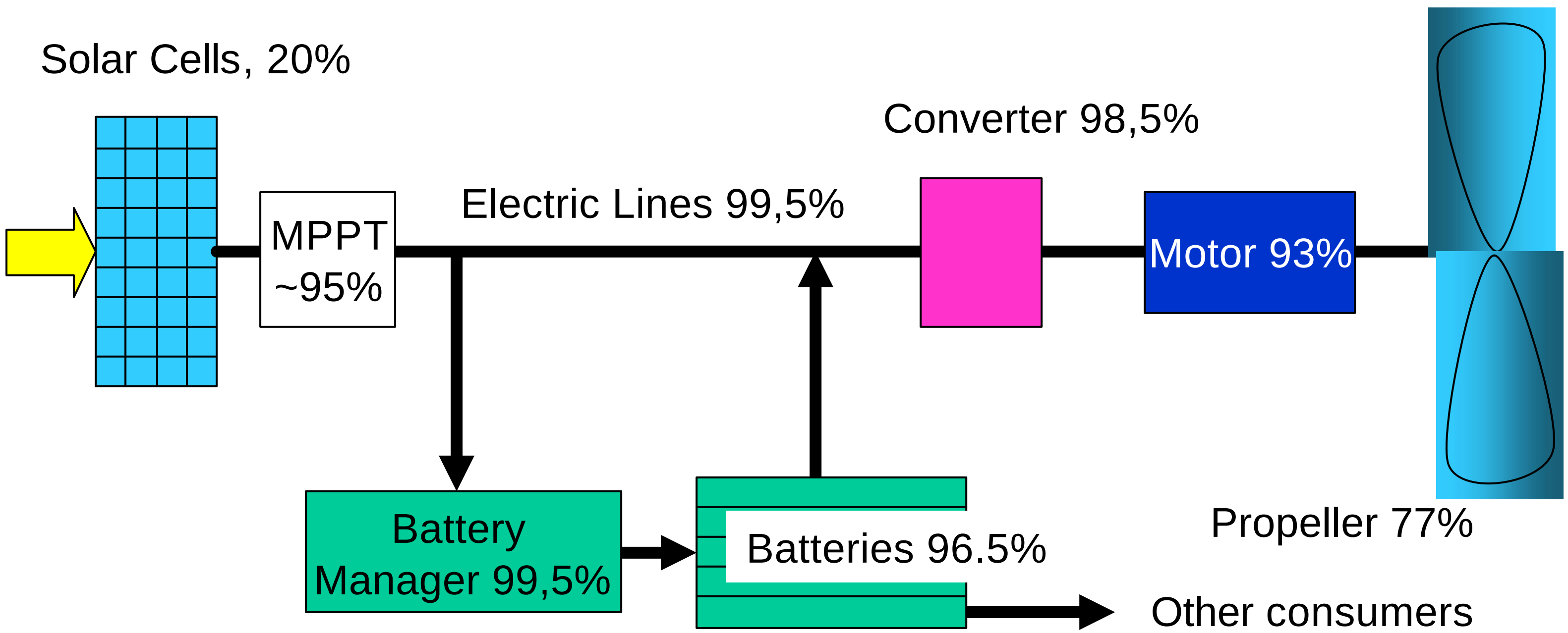
$$P = CD * \frac{r}{2} * V \wedge 3 * S$$

$$\frac{P}{S} = \sqrt[2]{\frac{2}{r}} * \left(\frac{W}{S}\right) \wedge 3/2 * \frac{CD}{CL \wedge 3/2}$$

$$\boxed{\frac{W}{S} = \left(\frac{P}{S}\right) \wedge (2/3) * \left(\frac{r}{2}\right) \wedge (1/3) * \frac{CL}{CD \wedge (2/3)}}$$

Power Train Schematic

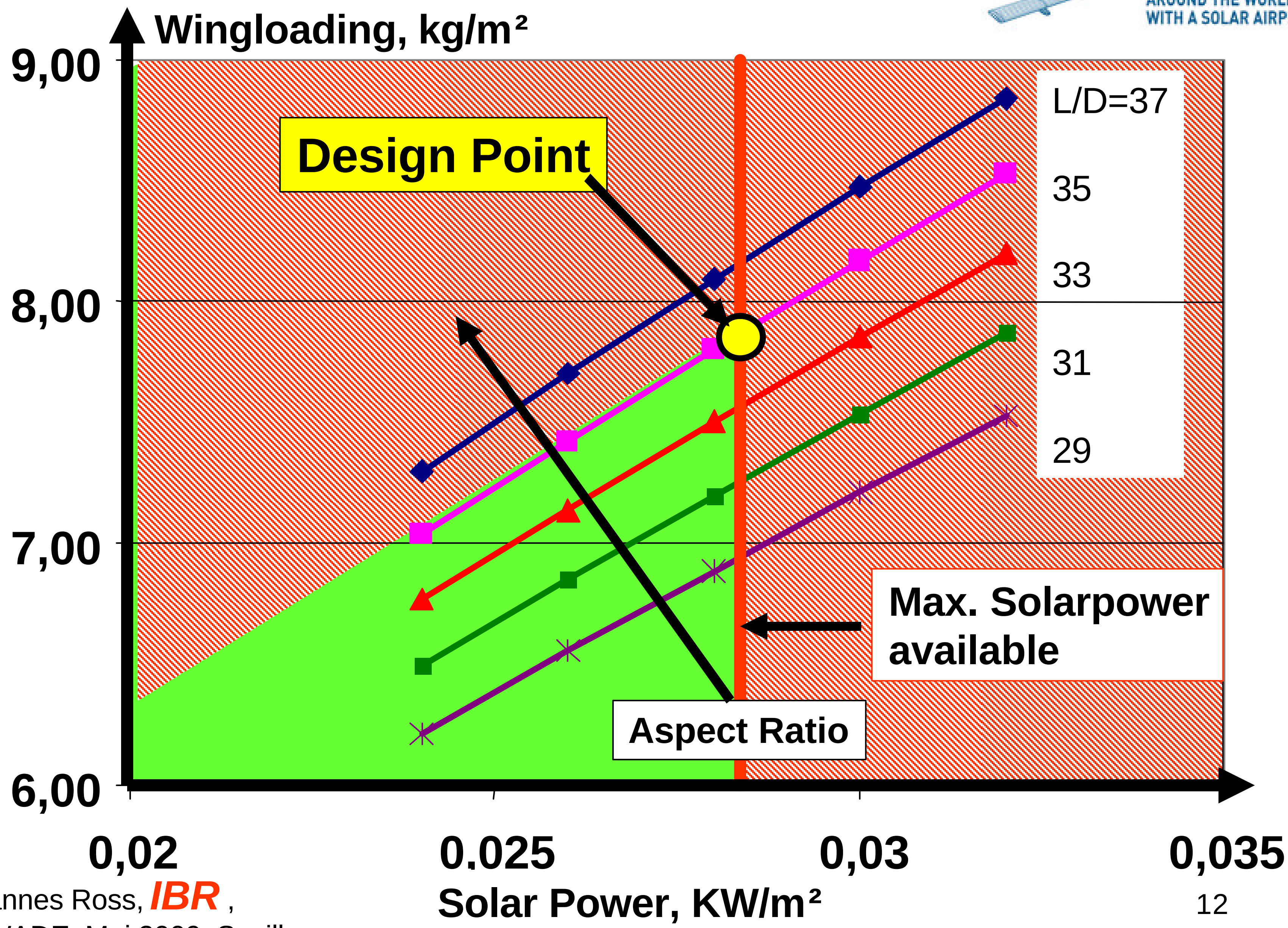
And Typical Losses/Efficiencies



From solar energy to propeller = 89% losses!!

MPPT= Maximum Power Point Tracker

Design Space



Contents

First Unmanned Solar Powered AC

Ray Bouchers „Sunrise1“, 1974

Gossamer Condor by P. McReady

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ECN-13413 Date: July 25, 1979 Photo by: Bob Rhine

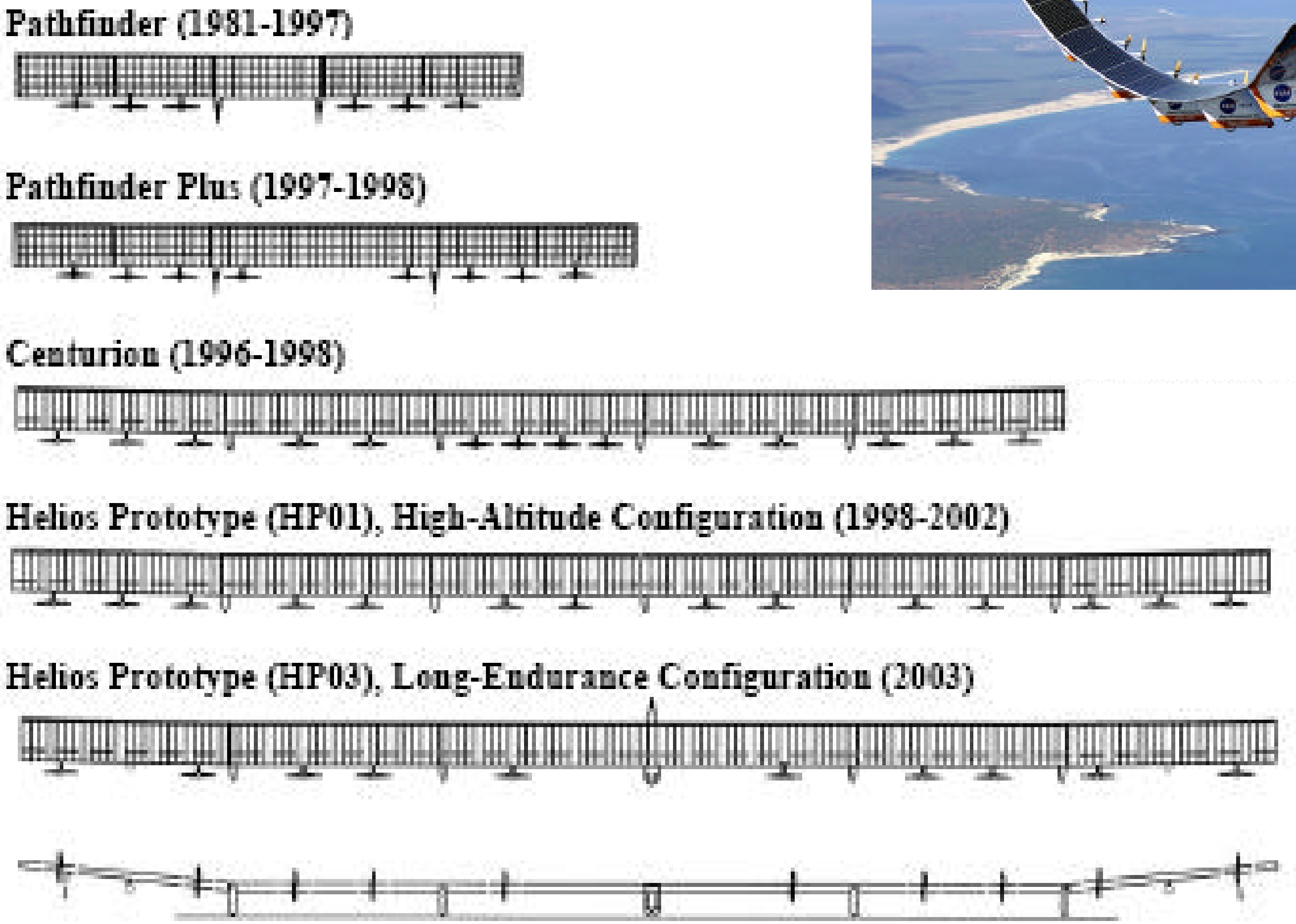
Solar-powered Gossamer Penguin in flight

Solar Aircraft History

1980 **1990** **2000**

Unmanned Solar Aircraft

NASA's Environmental Research Aircraft and Sensor Technology **(ERAST)** Program



75m Wingspan

First 48 hour flight of an UAV, 2005

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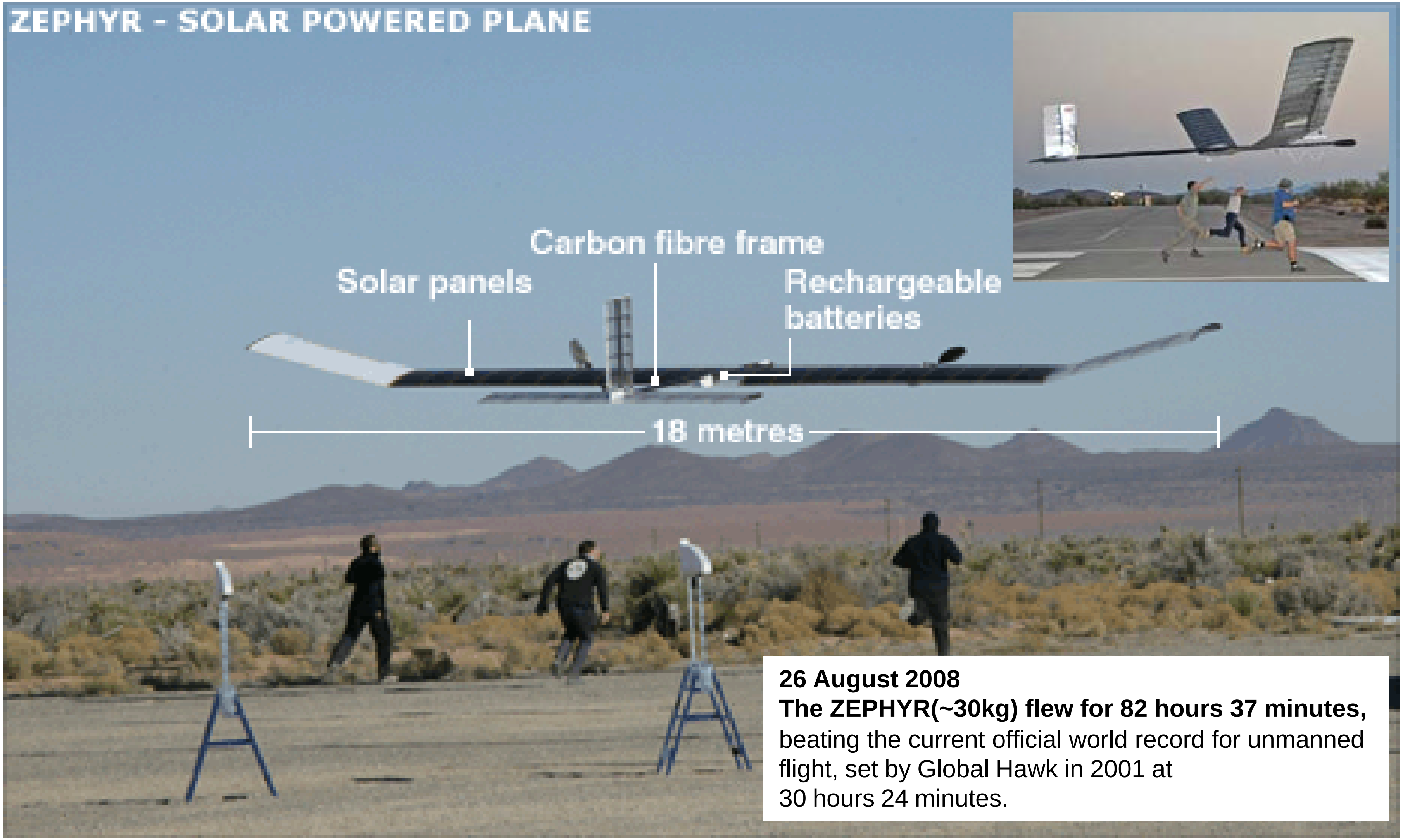
WITH A SOLAR AIRPLANE

AROUND THE WORLD WITH A SOLAR AIRPLANE

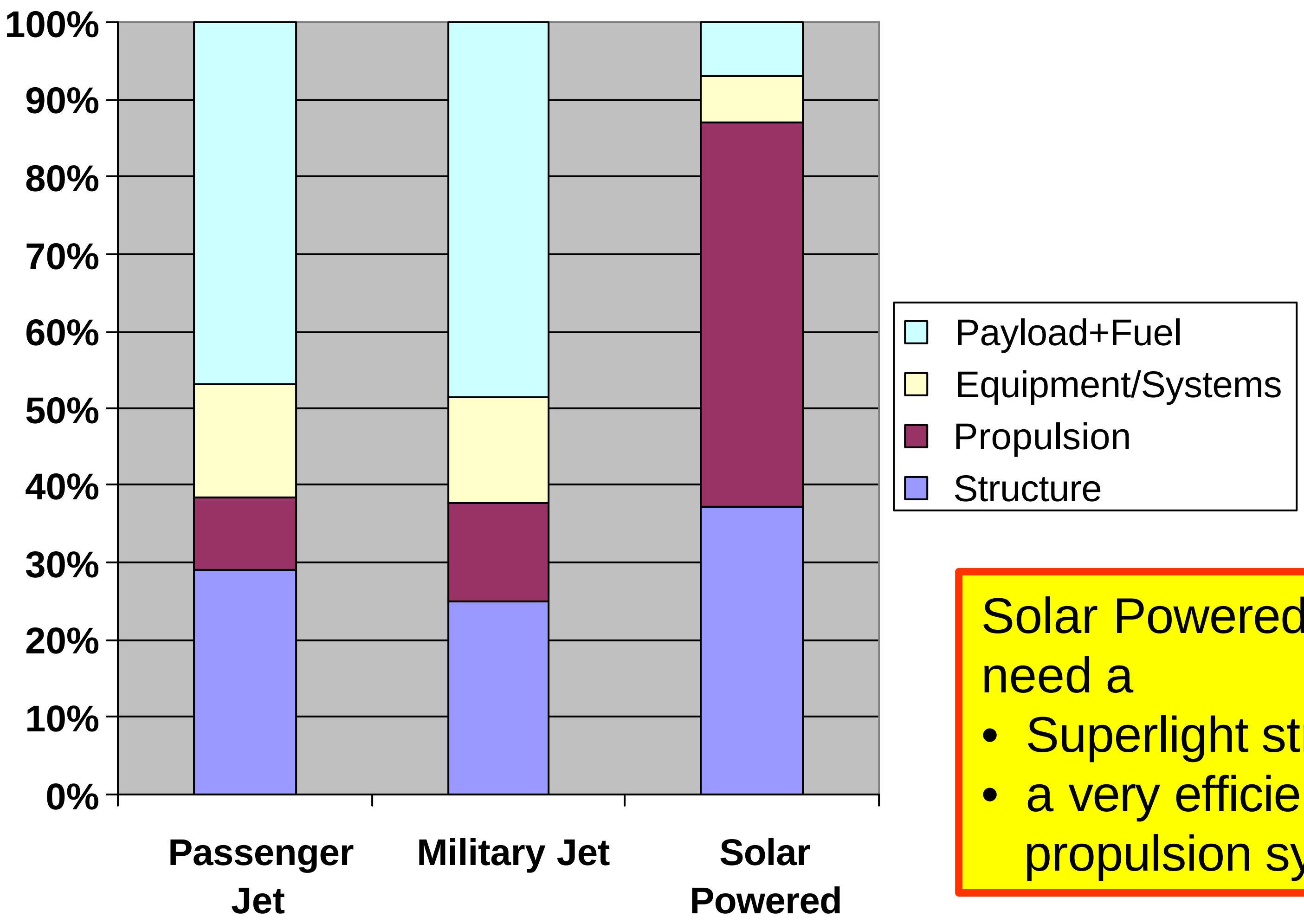


26 August 2008
The ZEPHYR(~30kg) flew for 82 hours 37 minutes, beating the current official world record for unmanned flight, set by Global Hawk in 2001 at 30 hours 24 minutes.

Contents

Relative Massbreakdown

Related to Maximum TOGW



Solar Powered AC need a

- Superlight structure
- a very efficient propulsion system

Technological Challenges

For manned ac with flight time >24 hr's

Propulsion

- **high specific power solar array >20%**
- **high specific energy batteries > 200 Wh/kg**
- **high efficiency electric motors**
- **high efficiency propeller**
- **thermal control systems for batteries, engines**

•Structures

- **lightweight composite structures**
- **acceptable aero-elastic characteristics**

Systems with Low Power Consumption

- **FCS, ECS, Communication, Navigation,**

Solar Cell Efficiency

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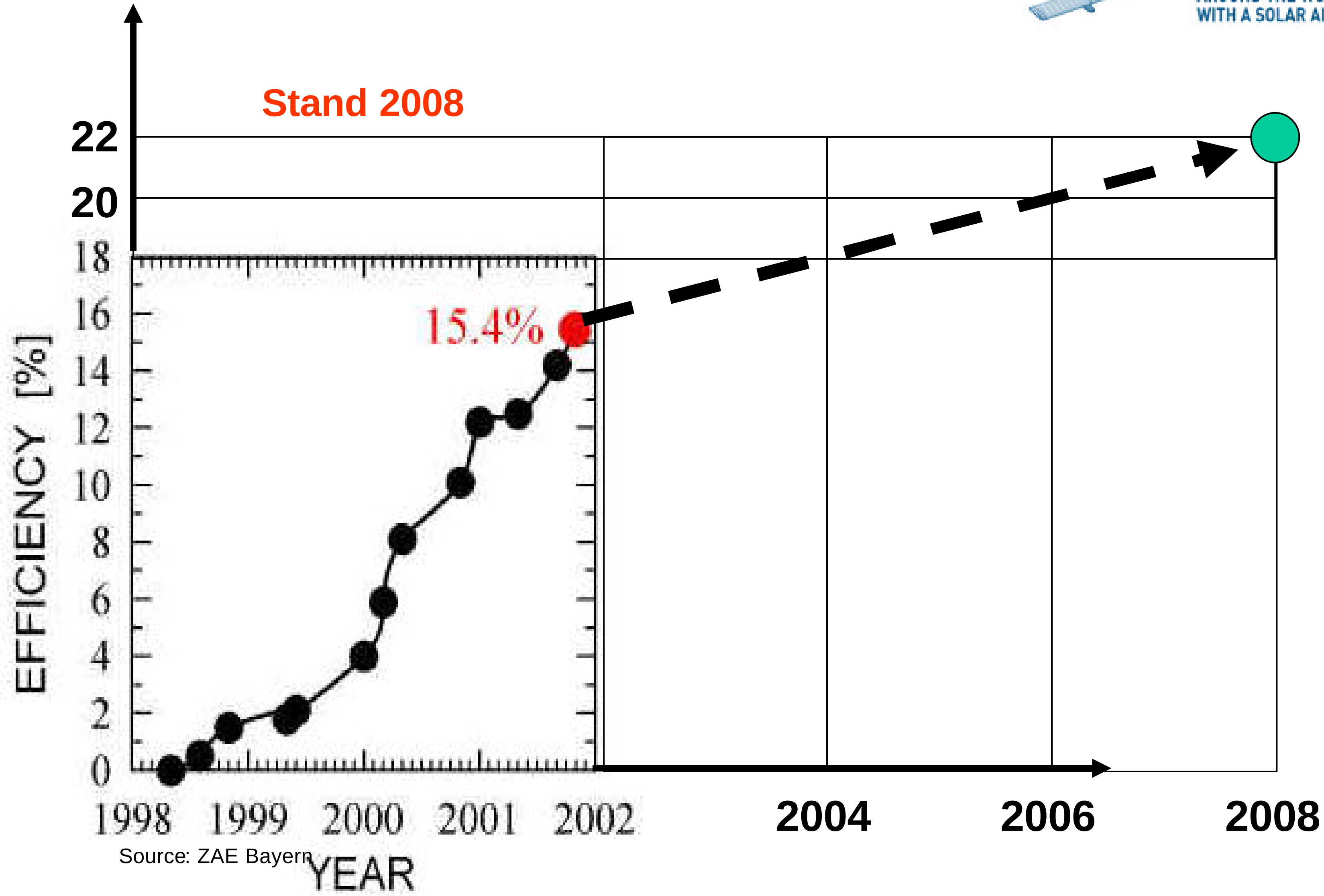
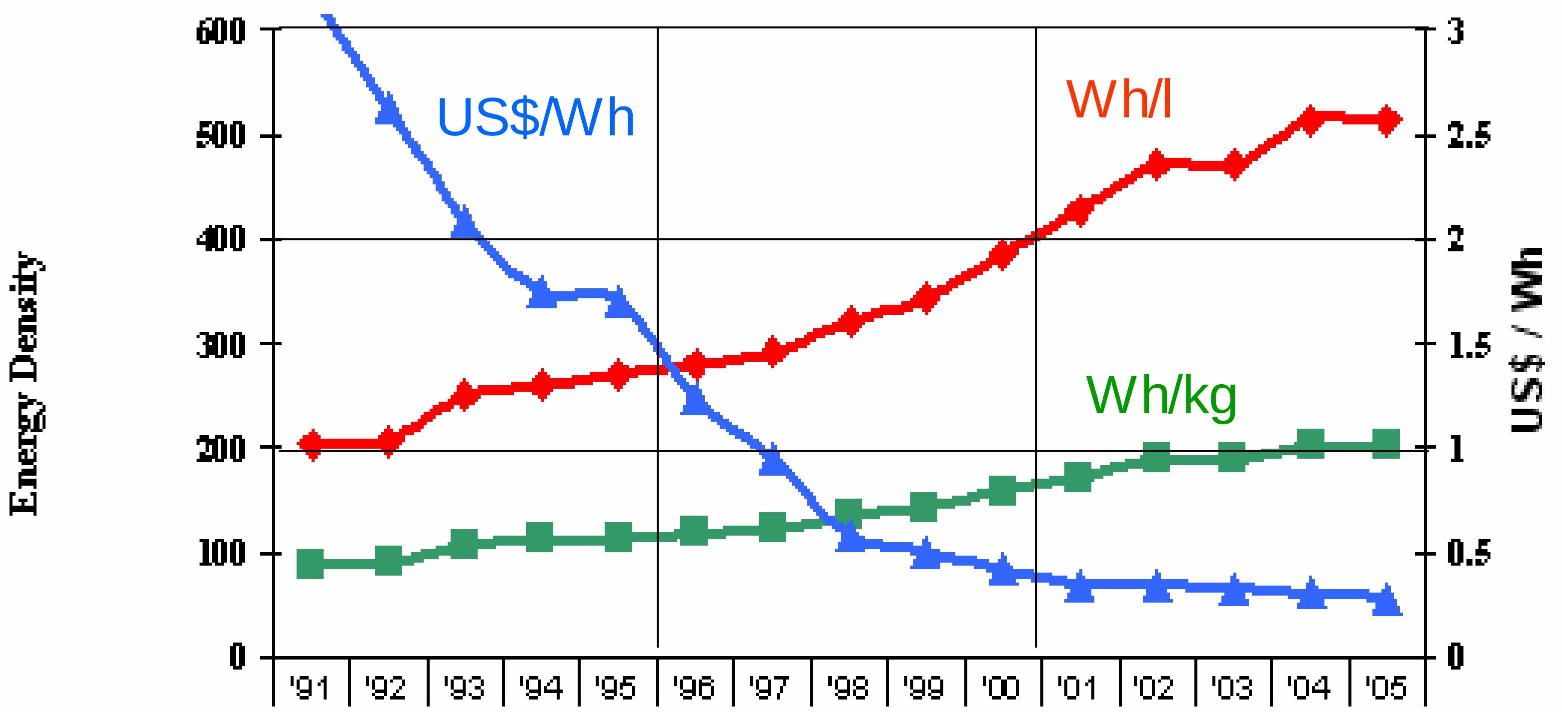


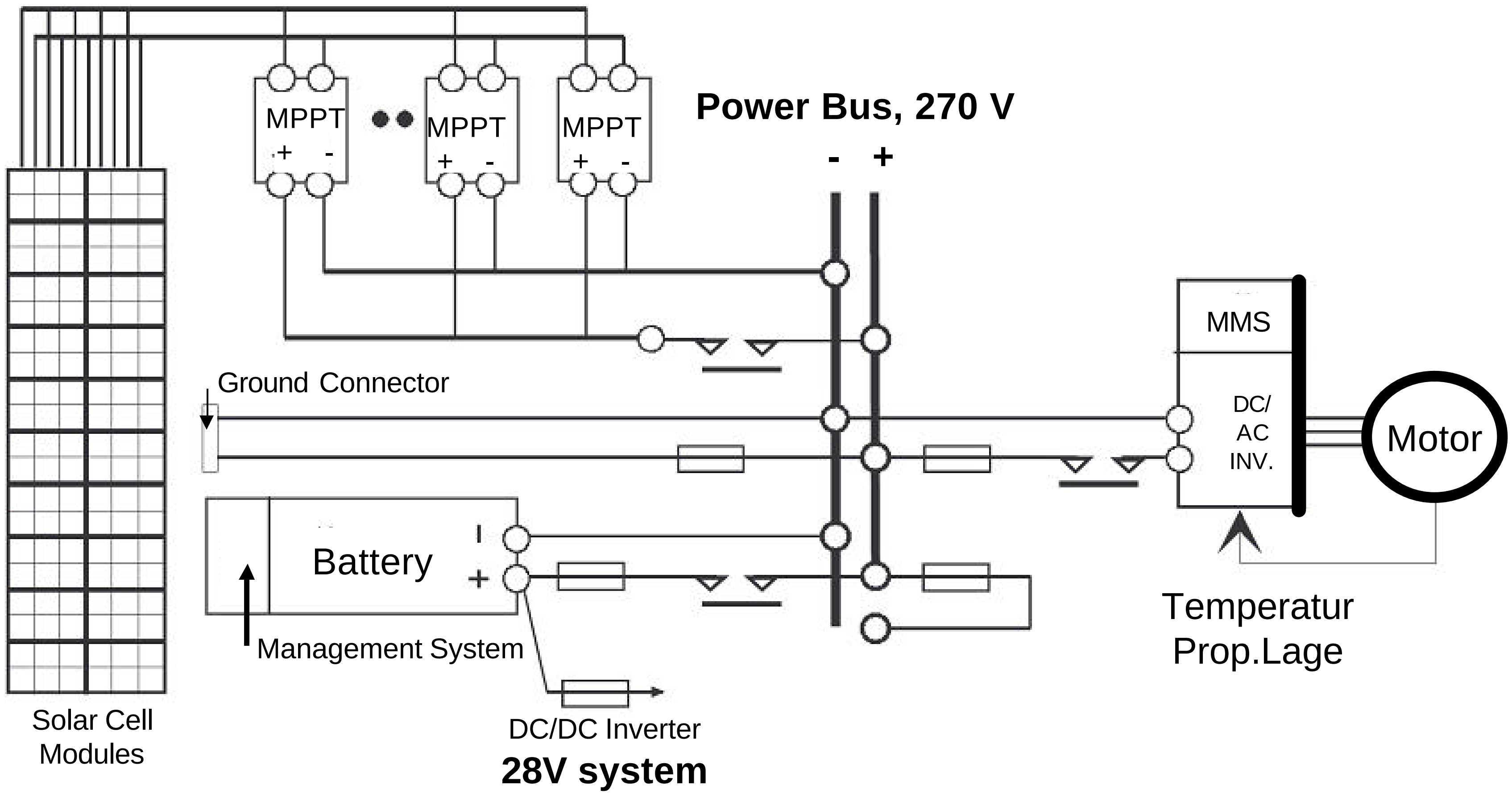
Source: ZAE Bayern

Lithium-Ion Battery Development



Source: www.battery university.com

Electrical System Schematic



Solar Power Generator

Typical Data

AROUND THE WORLD WITH A SOLAR AIRPLANE

Solar cell

Size: 125mm x 125 mm → ~ 60 cells/m² !
for a solar area of **200m² --> ~12 000 cells** !

Voltage: output varies with cell temperature and load ~**0,6 V**

Mass: 0,480 kg/m² → 96 kg /200m²

Structural Flexibility: **adapt to wing deformation, no load pick-up**

Solar Cell Arrangement **6**0 Module cordwise , 320 Cell/String = spanwise

Maximum Powerpoint Tracker (MPPT= electronic control unit):

1 MPPT can control up to 4 modules → ~36 **MPPT's for 200m²**

Battery Characteristics

Typical Data

AROUND THE WORLD WITH A SOLAR AIRPLANE

Voltage: **4,2 V fully charged, 3.2 V fully discharged**

Specific energy: ~ >**200 Wh/kg**

Number in Battery Pack: 290 (Max Voltage)/4,2 = **70 units**

Total Battery Capacity for an aircraft: **86 kWh**

Battery pack for Antares Sailplane

Total Battery Mass: → **436 kg**

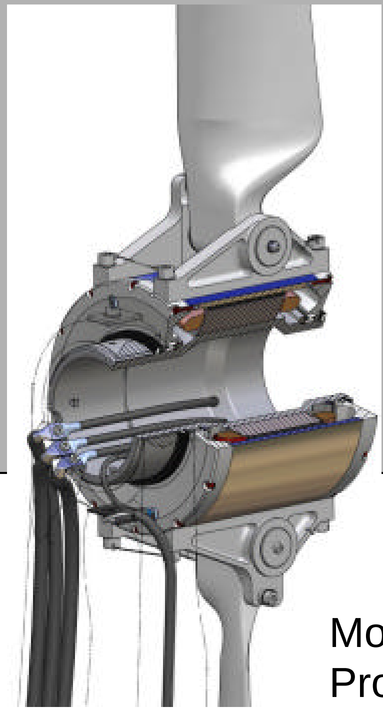
Battery Unit Capacity, Mass and Volume: **variable, →manufacturer**

Temperature: **15°C < T < 35°C, requires monitoring & conditioning**

Electrical Motors

- High efficiency
- Low weight (higher RPM→transmission system), low volume
- Good RPM controllability
- Operational between -50°C to 110° C

- Type's
  - **DC**
  - **Asynchron**
  - **Synchron**
  - **Transversalflow**



Motor for Antares Sailplane 42 KW, Propeller diameter 2m

Structural Design

- **Specific wing mass ~ 2kg/m²**
- **No statistical data available!!**
- **Ground handling is a tricky**

<u>Primary materials:</u>
- Carbon Fibre Composites,
- Foam,
- (Transparent) plastic skin/foil

<u>Structural concepts</u>
- Tubular- / Box - Spar
- Sandwich
- Grid structure

Dryden Flight Research Center EC96-43765-8 Photographed November 1996
LIGHT AS A FEATHER--Technicians easily lift a 20-foot wing section during assembly of the Pathfinder solar-powered aircraft. NASA photo by Dennis Taylor

Helios, normal wing bending at 1g

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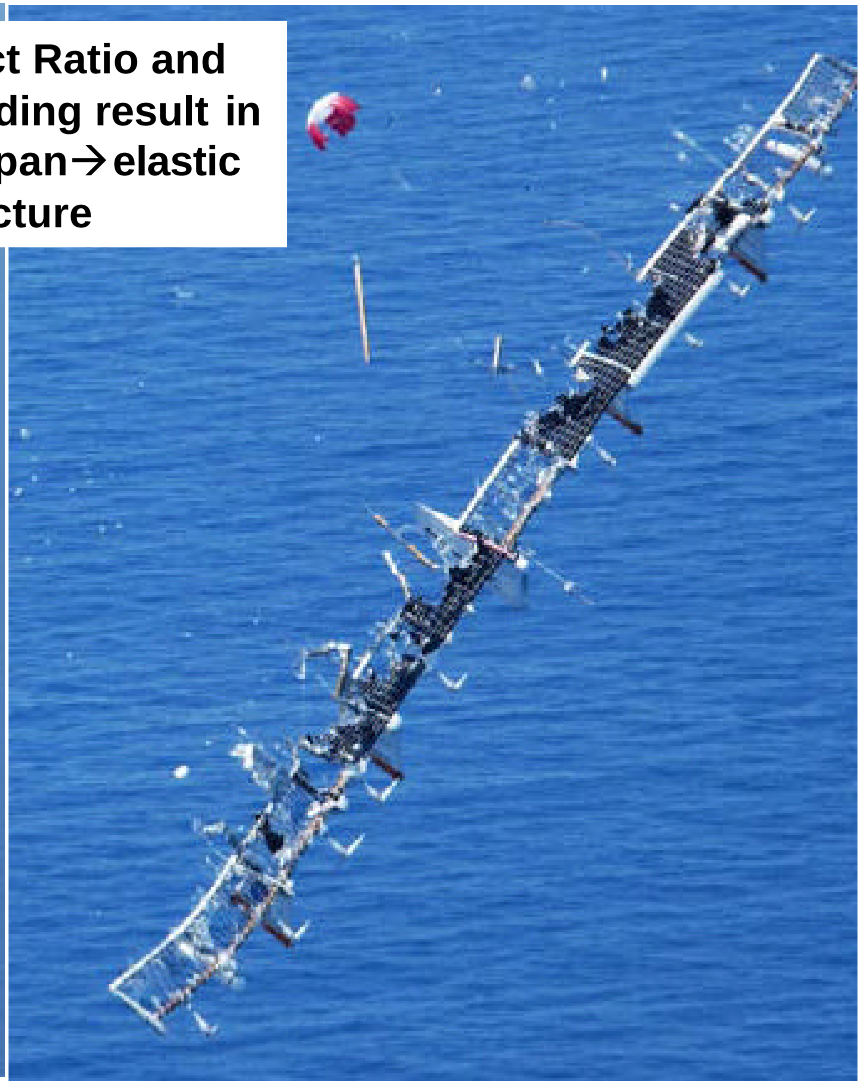
WITH A SOLAR AIRPLANE

Helios Accident

High Aspect Ratio and low wing loading result in high wing span→elastic structure



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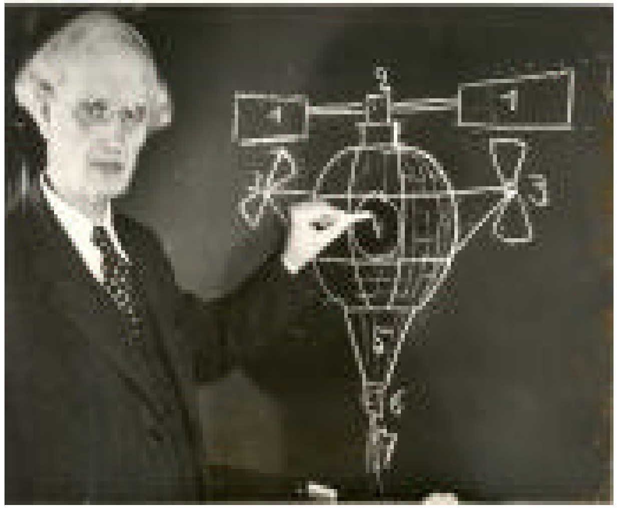
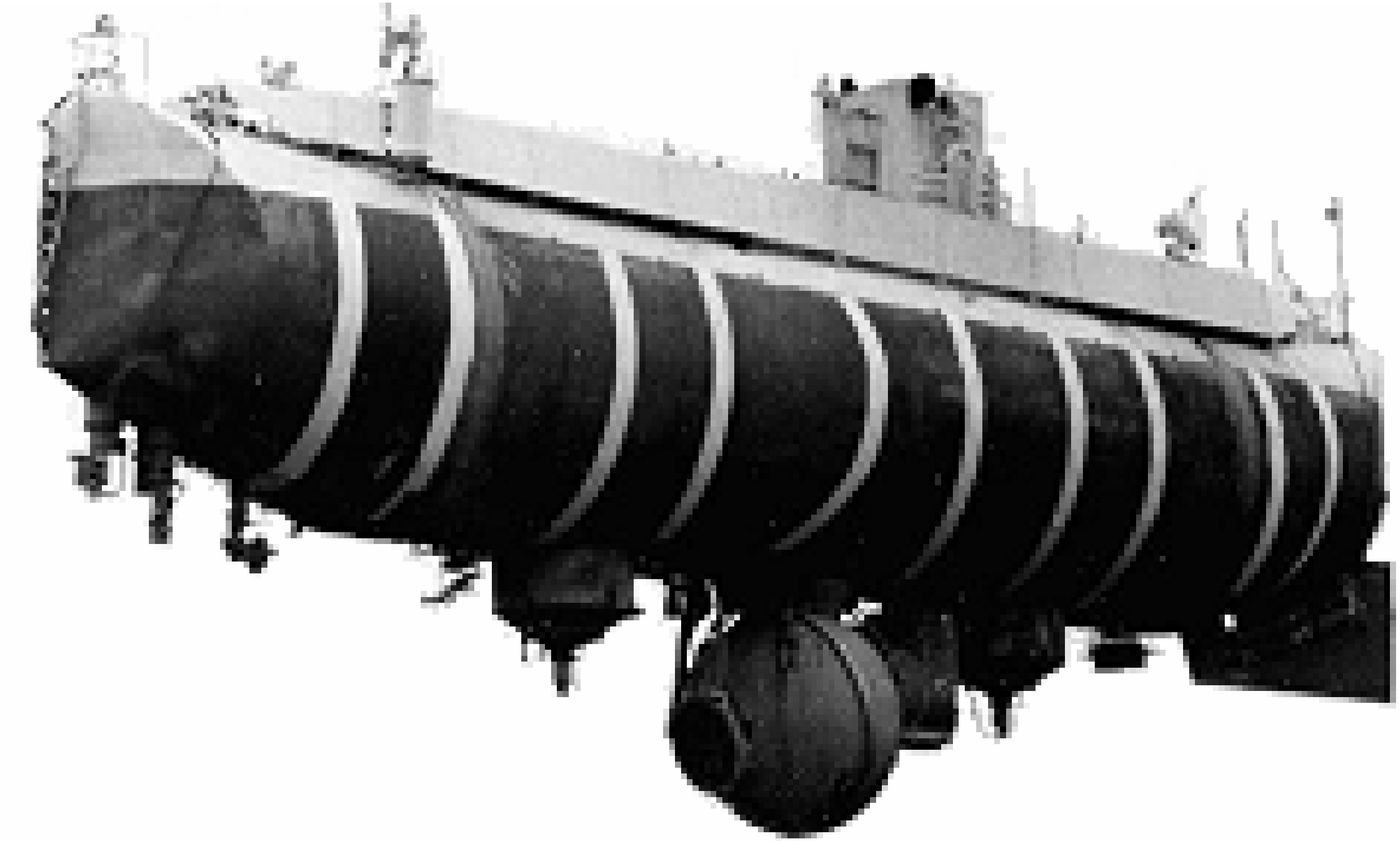
WITH A SOLAR AIRPLANE



18.08.1932: Der schweizerische Physiker Auguste Piccard (1884-1962) erreicht mit seinem Ballon »FNRS« eine Höhe von 16.940 m
und dringt damit in die Stratosphäre vor. Piccard und der Physiker M. Cosyns sitzen dabei in einer kugelförmigen Druckkabine. Die Forscher führen Strahlungsmessungen durch und beweisen die Ungefährlichkeit des Aufenthaltes in größeren Höhen für Menschen in Druckkabinen - eine wichtige Erkenntnis für den Luftverkehr.



Am 23. Januar 1960 tauchte der Amerikaner mit dem Schweizer Jacques Piccard in die "Challenger-Tiefe", knapp 400 Kilometer südwestlich der Pazifik-Insel Guam. Mit knapp 11.000 Metern ist sie einer der Kandidaten für den tiefsten Punkt der Erde. Das Fahrzeug, ein Bathyscaph namens "Trieste", hatte Piccard gemeinsam mit seinem Vater Auguste im Jahre 1953 entwickelt und 1959 an die US-Navy verkauft. Als die Navy ein Jahr später zum Tiefen-Rekord ausholte, übertrug sie Don Walsh das Kommando.

Bertrand Piccard decided to launch into a new futuristic enterprise:
to fly round the world in a solar-powered aeroplane

Solar Impulse Program

AROUND THE WORLD
WITH A SOLAR AIRPLANE

Initiated 2001 by
Bertrand Piccard and
André Borschberg

<u>Objective:</u>

Develop a manned solar powered aircraft
which can fly around the world with solarpower only

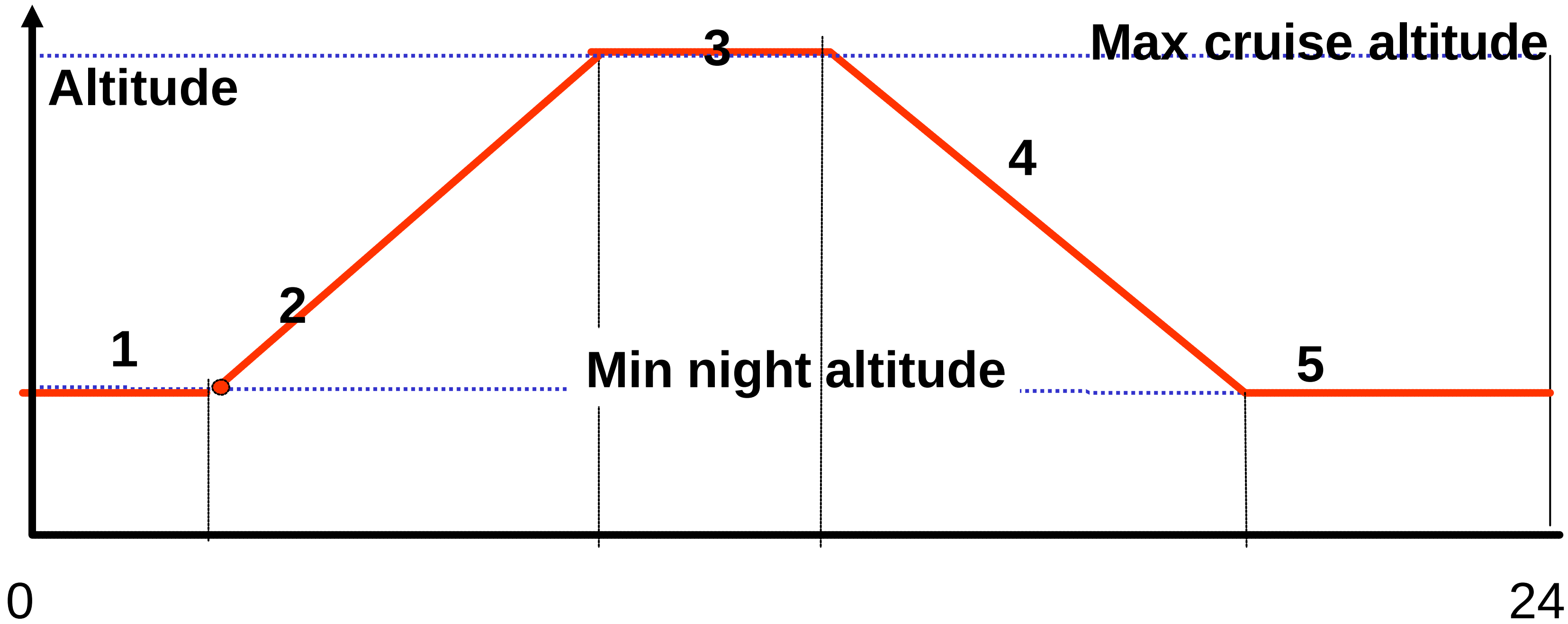
Feasibility Study 2002-2003

<u>Approach:</u>

Develop a „Demonstrator“ aircraft to show a 24hr energy neutral day and night
Cycle → HB-SIA

Develop the „Record“ aircraft, capable of
crossing Atlantic, Pacific in 4 to 5 day`s and
fly around the world in 5 to 6 legs

Mission Profile



1. Fly at minimum night altitude
2. Climb
3. Cruise at at max altitude,if power is available
4. Descent at available power
5. Fly at minimum night altitude

Relative Flight Power Required and Solarpower generated=f(Altitude)

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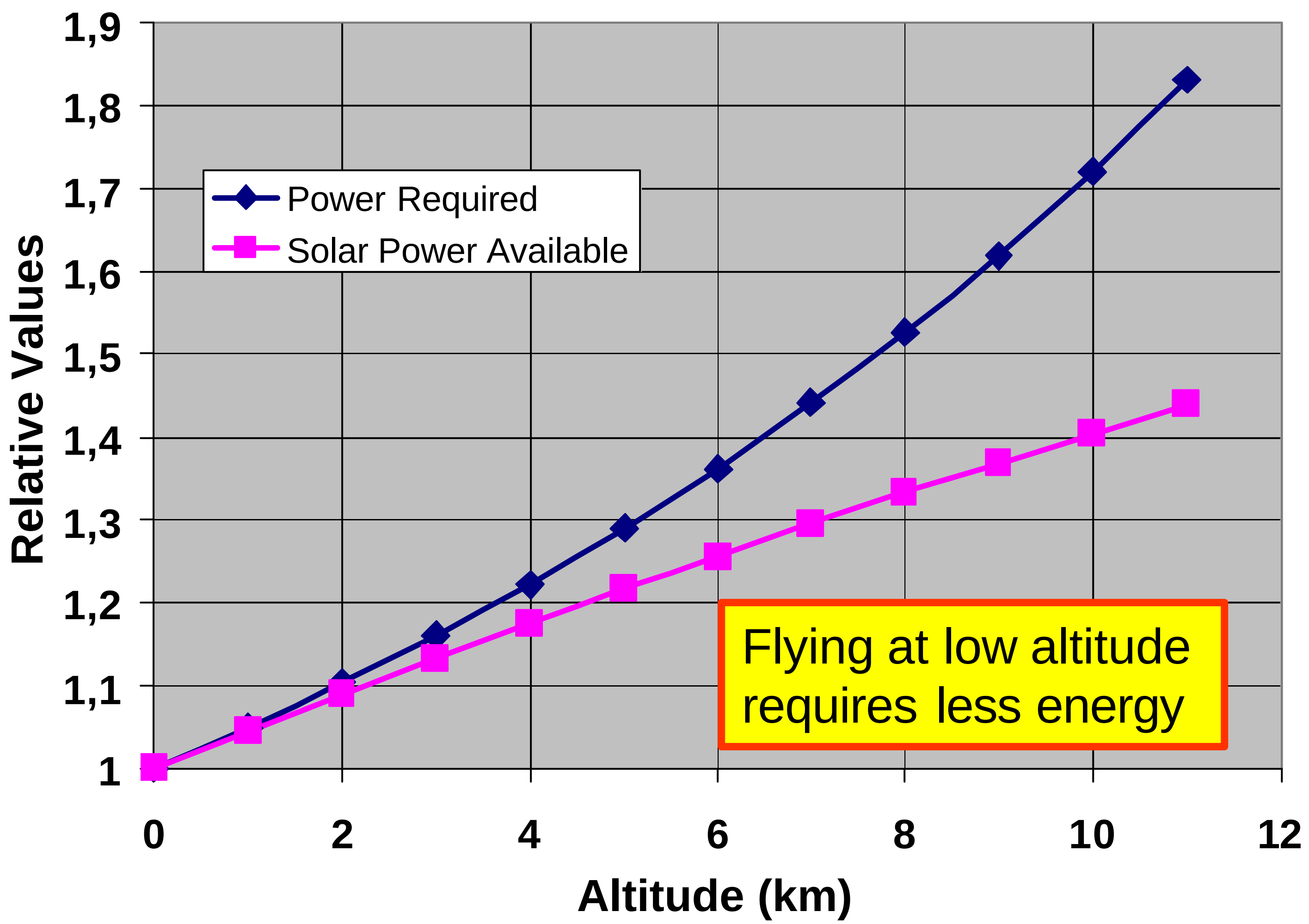
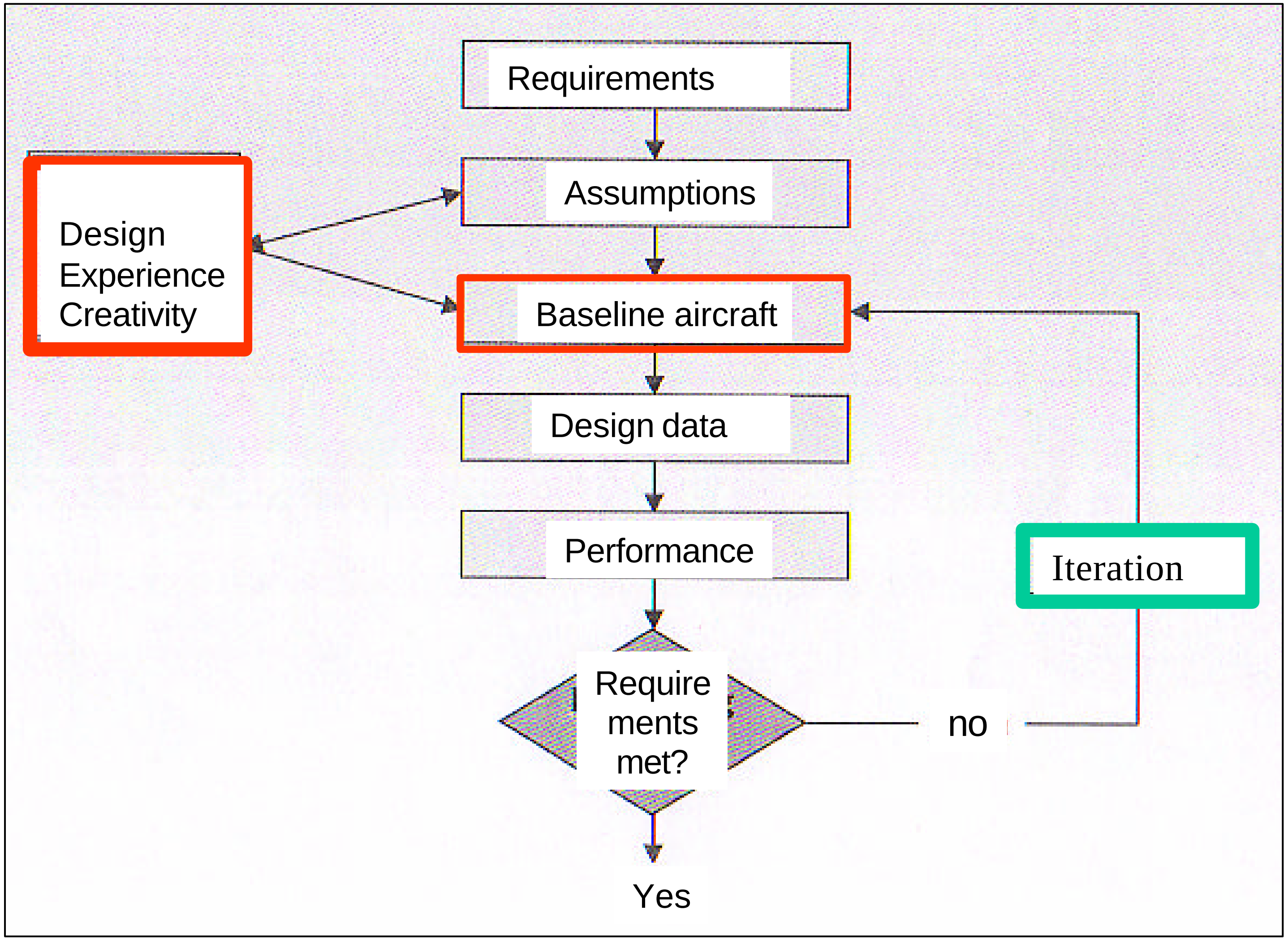


Typical Configuration

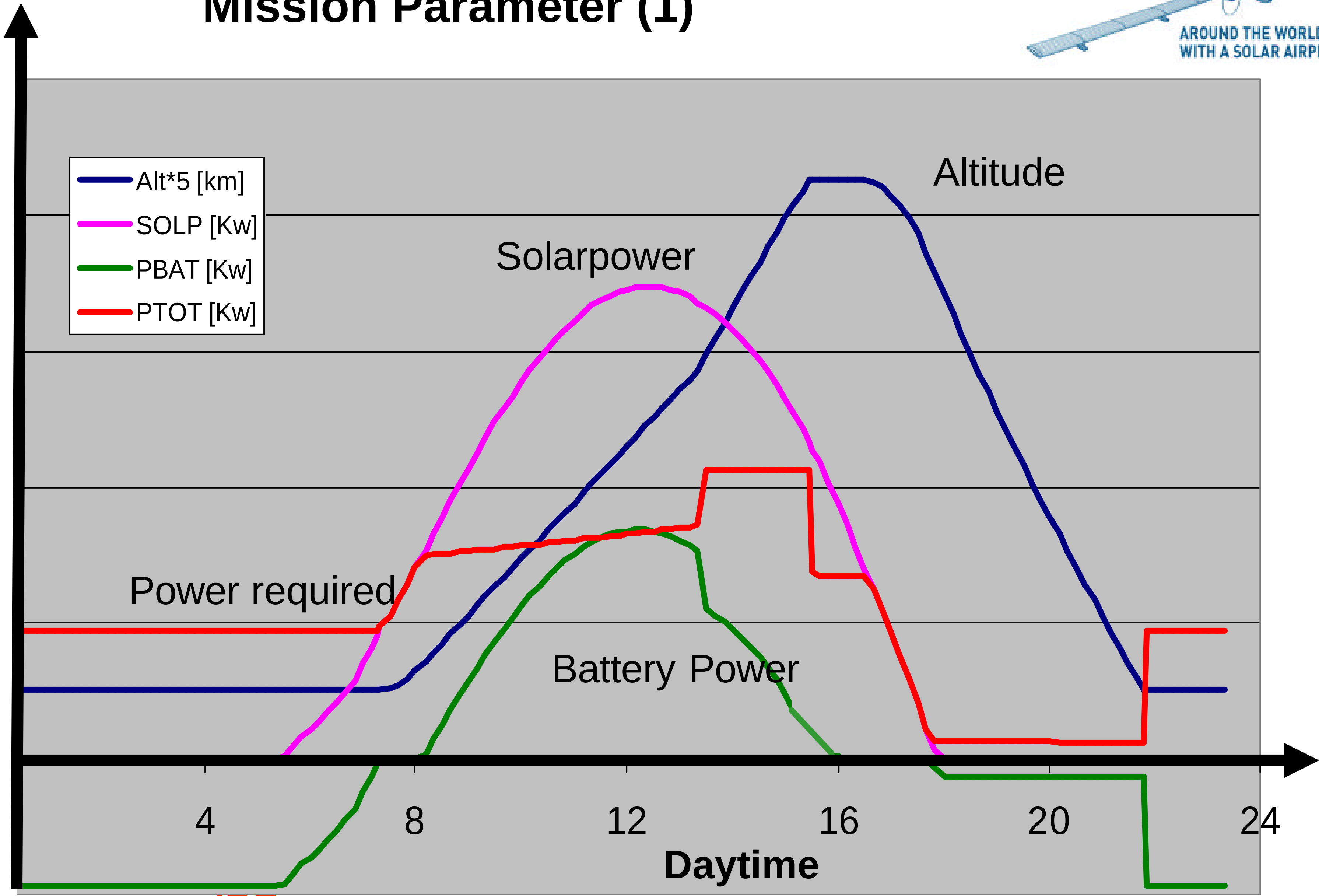
AROUND THE WORLD
WITH A SOLAR AIRPLANE

- Conventional configuration
- Main weight in wing (partially span loaded aircraft)
- Ultra low wing loading (~ 8 kg/m²)
- Design optimized for : low power loading, high aerodynamic and propulsion efficiencies
- Carbon epoxy HM & HT ultra light primary structures

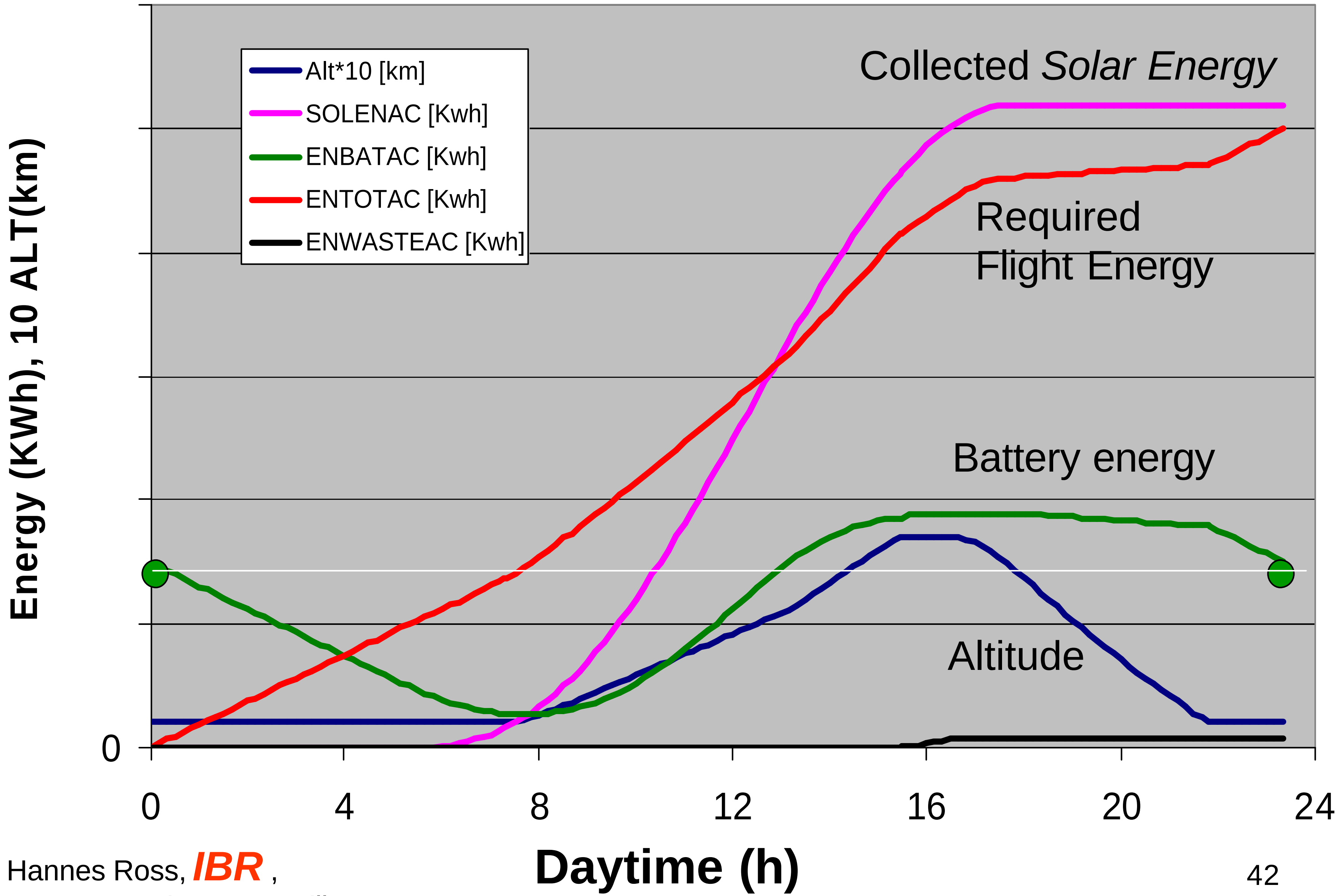
Design/Scaling Program



Mission Parameter (1)



Mission Parameter (2)



Design Space

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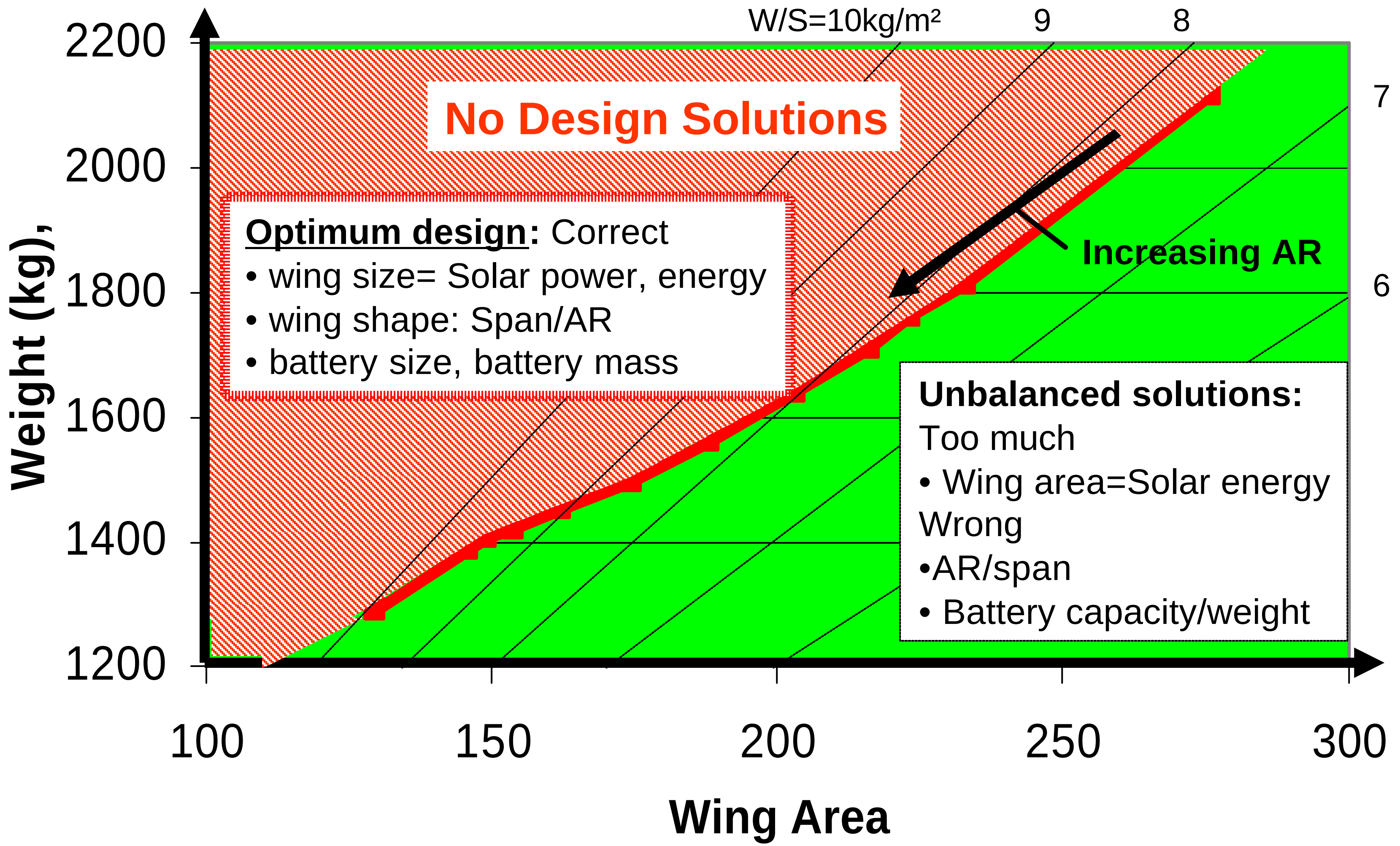
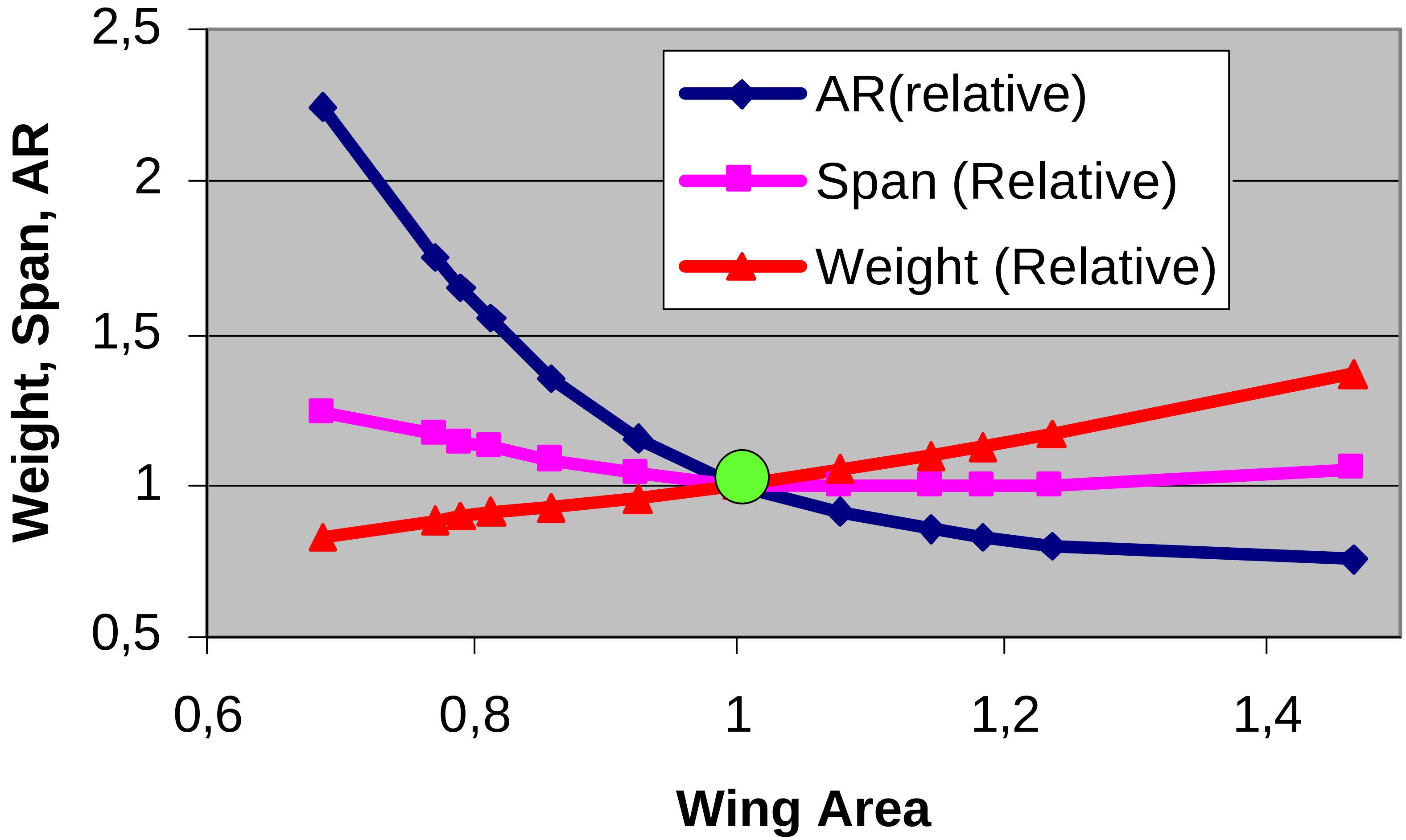
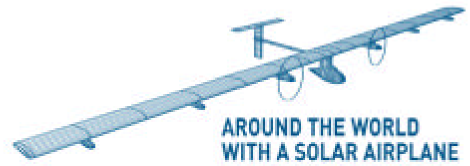
WITH A SOLAR AIRPLANE

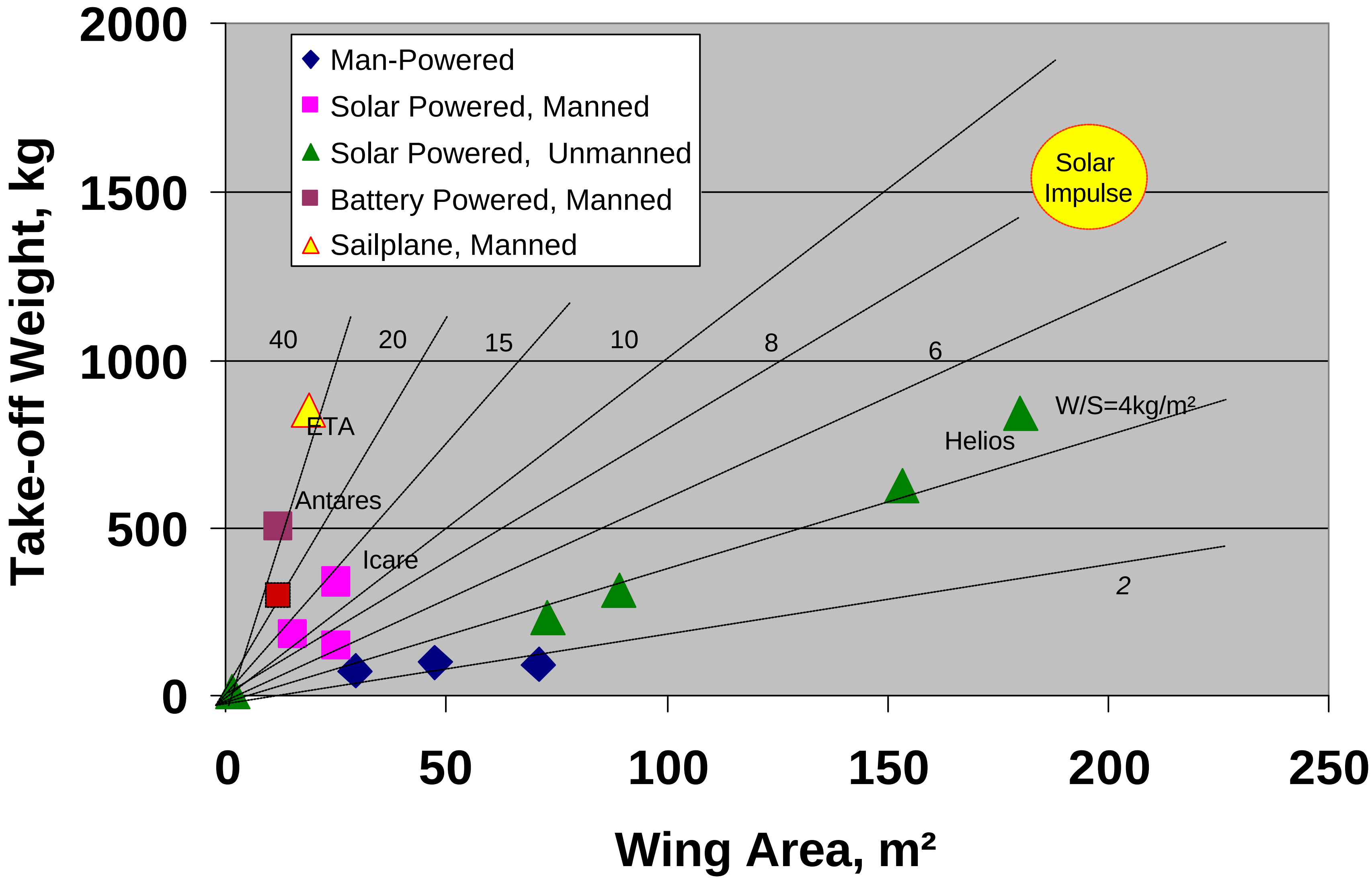


Optimum Design Solutions

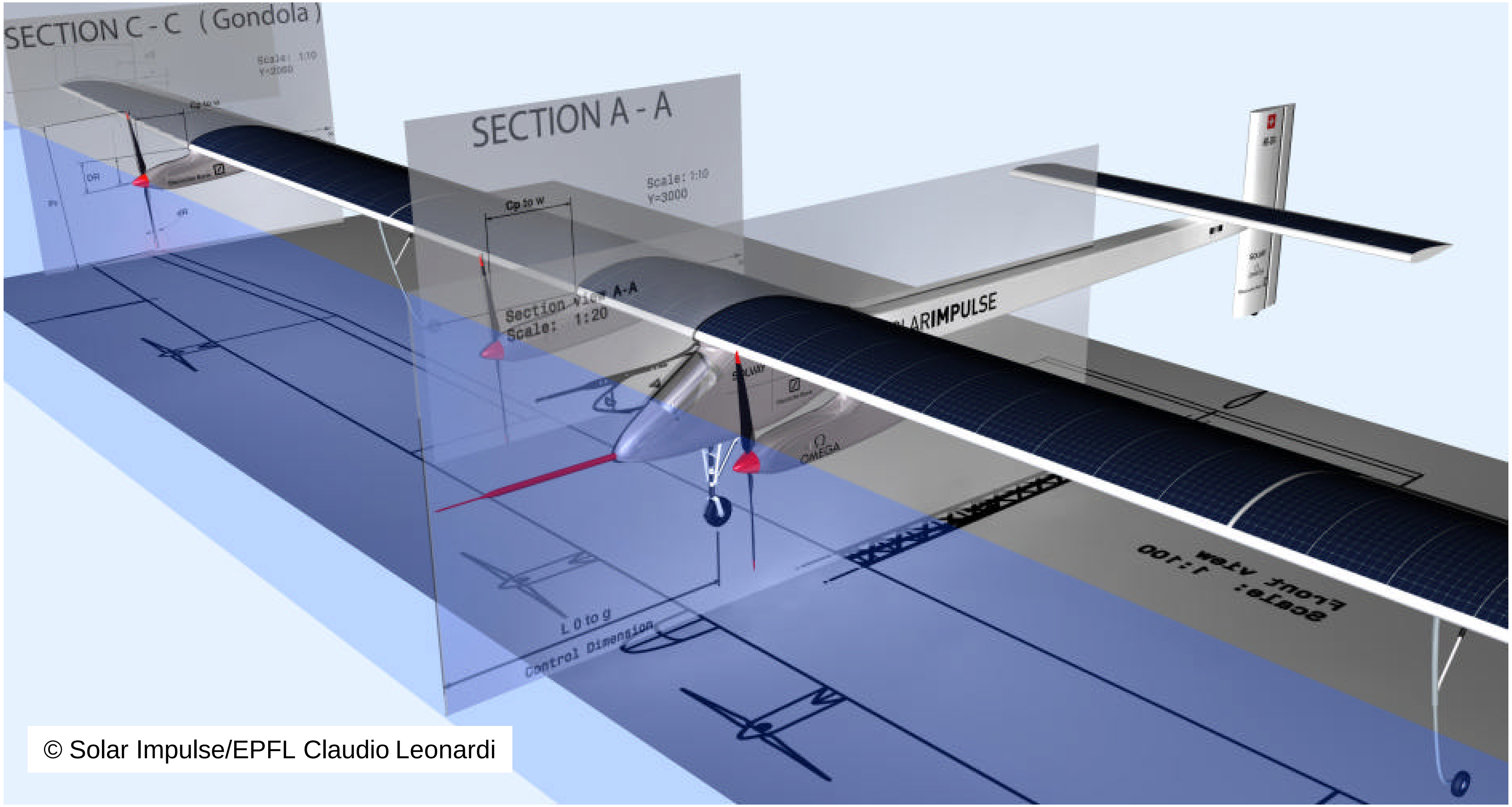


Take-off Weight and Wingloading

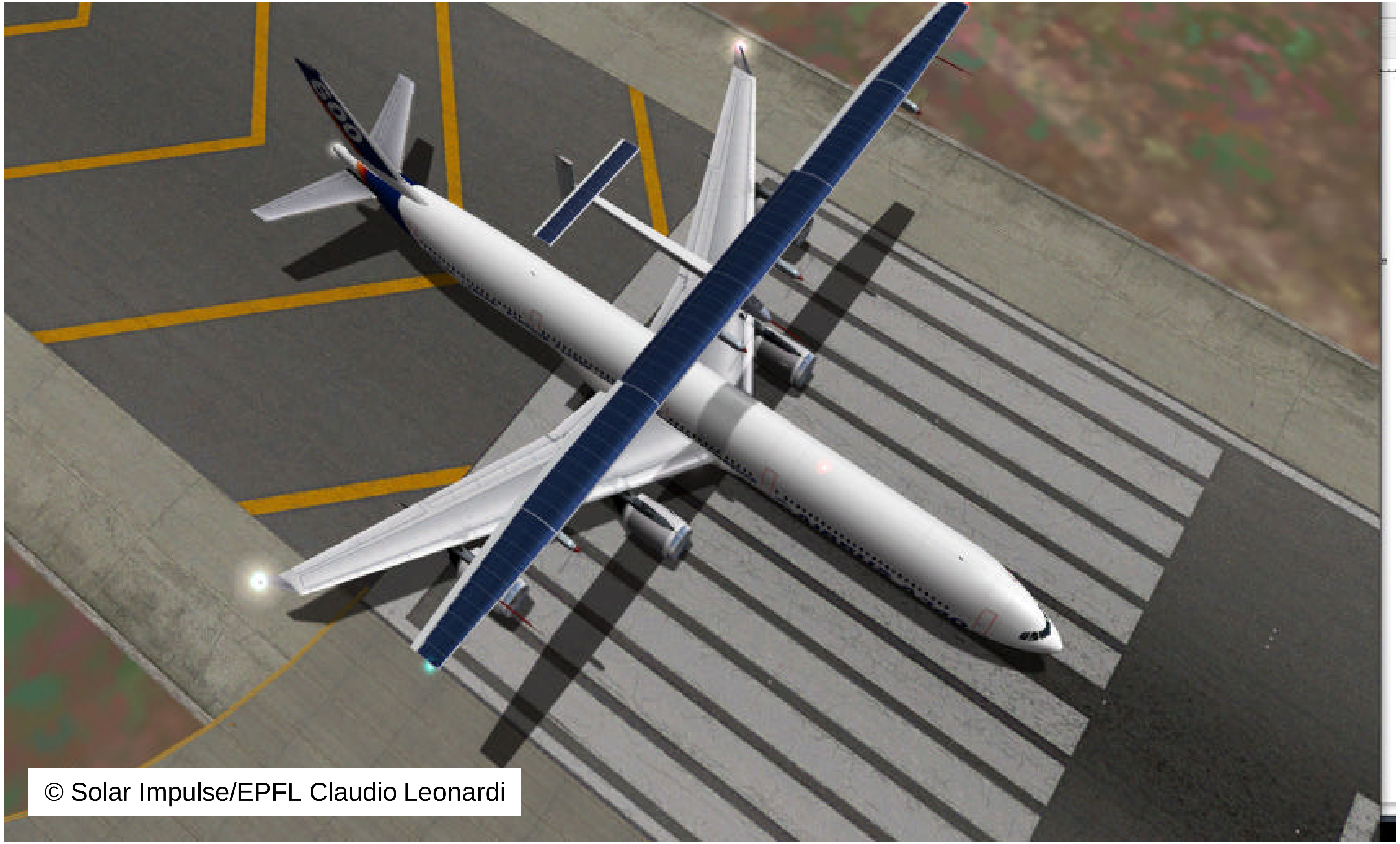




SI Prototype Aircraft HB-SIA



© Solar Impulse/EPFL Claudio Leonardi



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Test Fixture for 10m Wingbox

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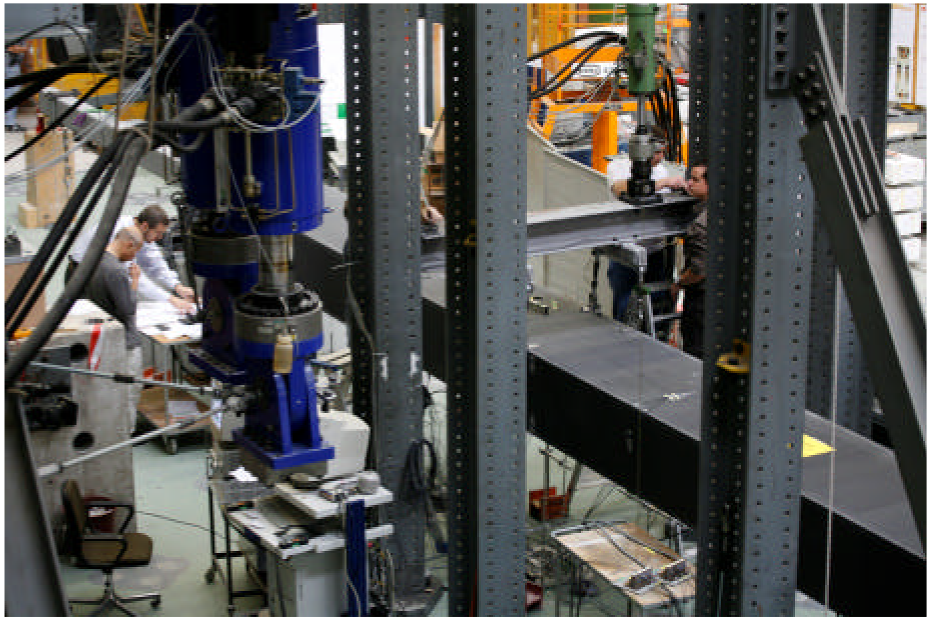
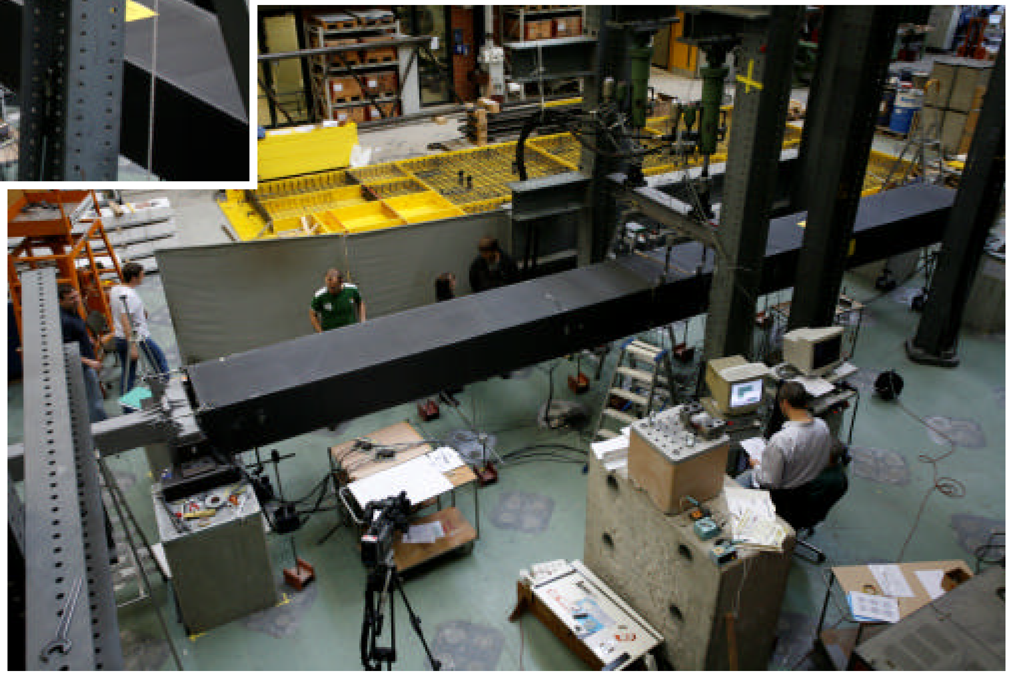
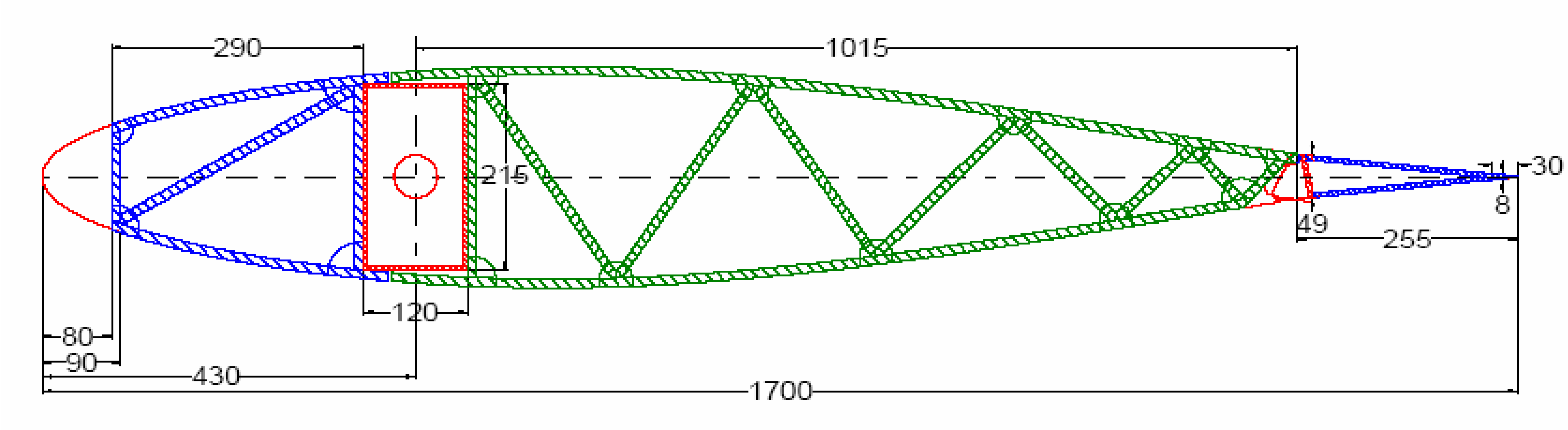




Source. SOLAR iMPULSE

Example: Horizontal Stabilizer

Test article of 2.6m*1.7m



Source. SOLAR iMPULSE

Example: Horizontal Stabilizer

Test article of 2.6m*1.7m

Source. SOLAR iMPULSE

Cockpit Structure:

CFC sandwich
and foam shell

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WITH A SOLAR AIRPLANE

Inside the gondola © SI/Stéphane Gros

Gongola Structure and Engine

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WITH A SOLAR AIRPLANE

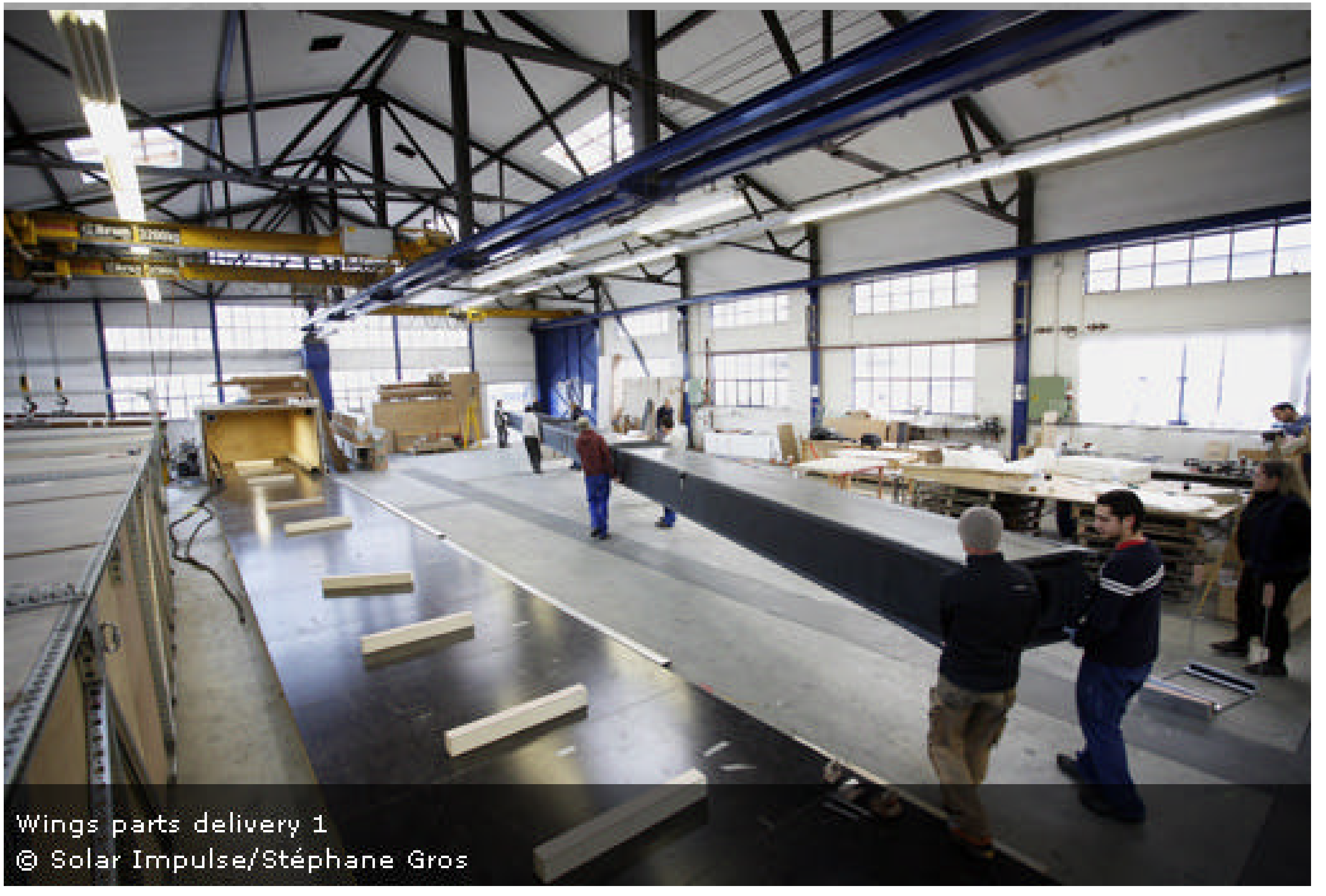
Gondola without the propeller © SI/Stéphane Gros


Gondola test © SI/Stéphane Gros

© Solar Impulse/Stéphane Gros

© Solar Impulse/Stéphane Gros


Tail boom © SI/Stéphane Gros



Wings parts delivery 1

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The 3 parts of the wing assembled
© Solar Impulse/Stéphane Gros

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Vibration tests
© Solar Impulse/Stéphane Gros


Plane skeleton assembled for vibration tests
© Solar Impulse/Stéphane Gros


Vibration tests
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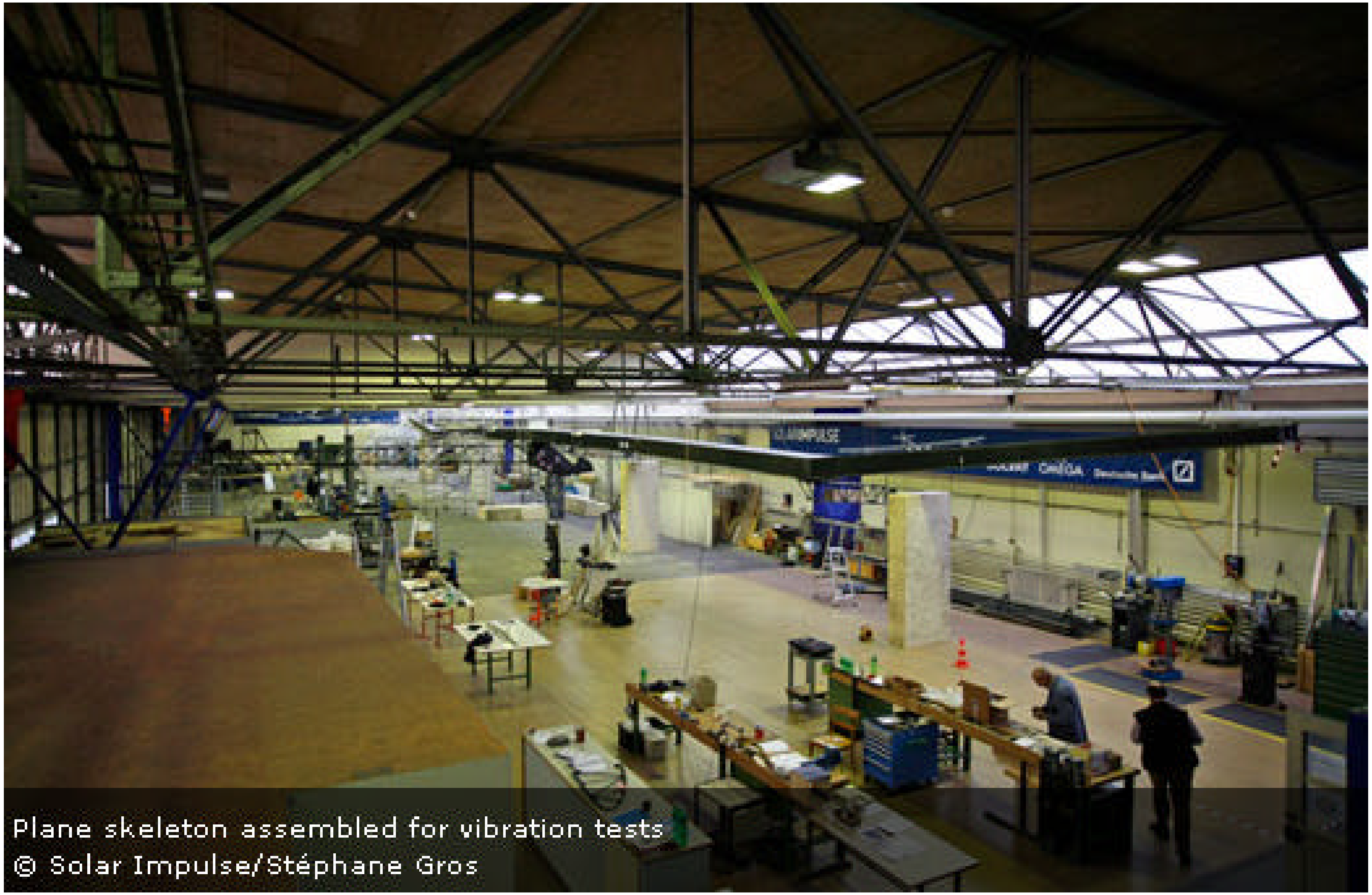
Plane skeleton assembled for vibration tests
© Solar Impulse/Stéphane Gros


photo gallery
Plane skeleton assembled for vibration tests
© Solar Impulse/Stéphane Gros

Cockpit

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Loading tests
© Solar Impulse/Stéphane Gros


E
F
G
H
I
J


Men at work on photovoltaic cells © SI/Stéphane Gros

Where shall we fly? (21 June)

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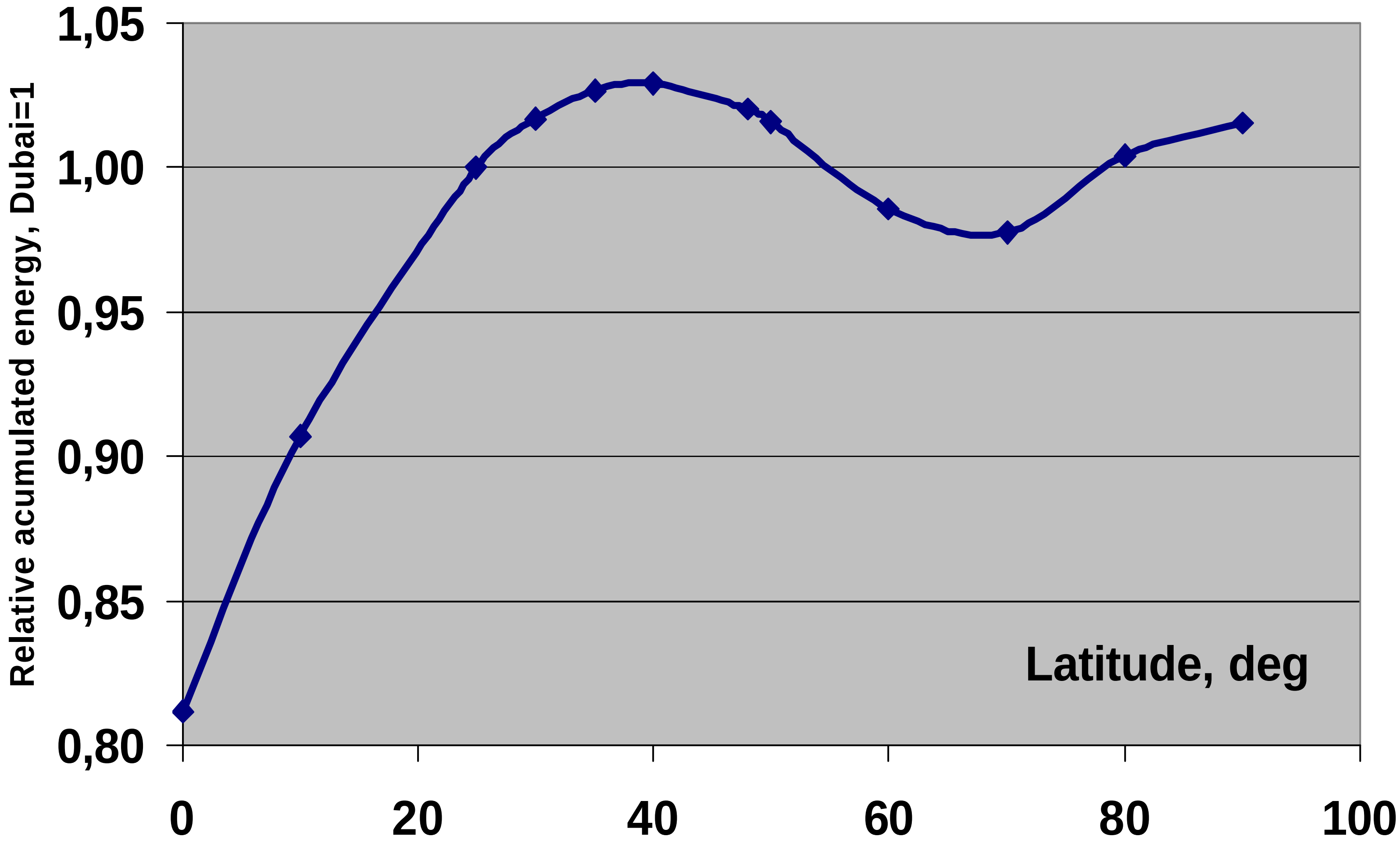

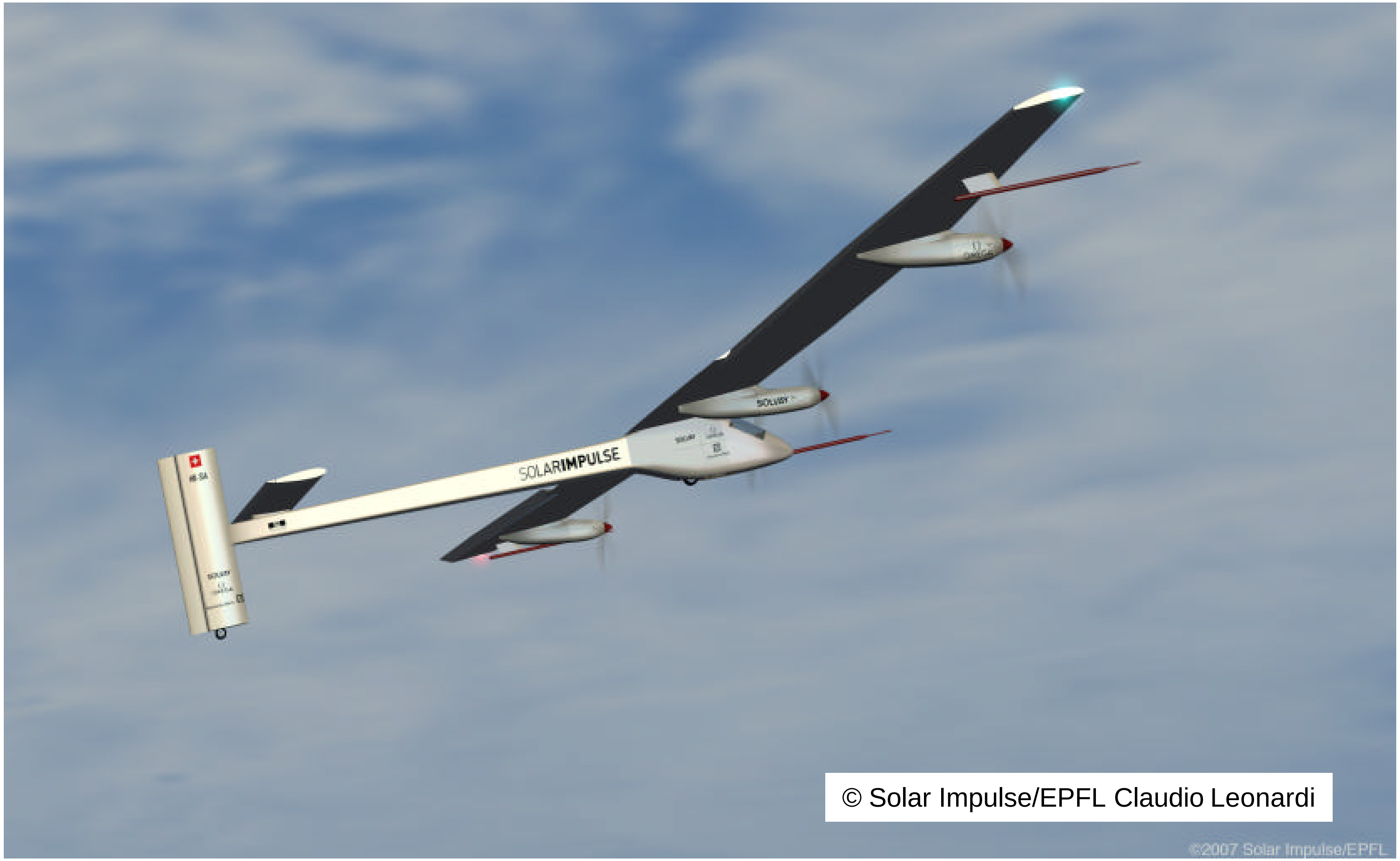
SOLARIMPULSE
SOLVAY
© Solar Impulse/EPFL Claudio Leonardi
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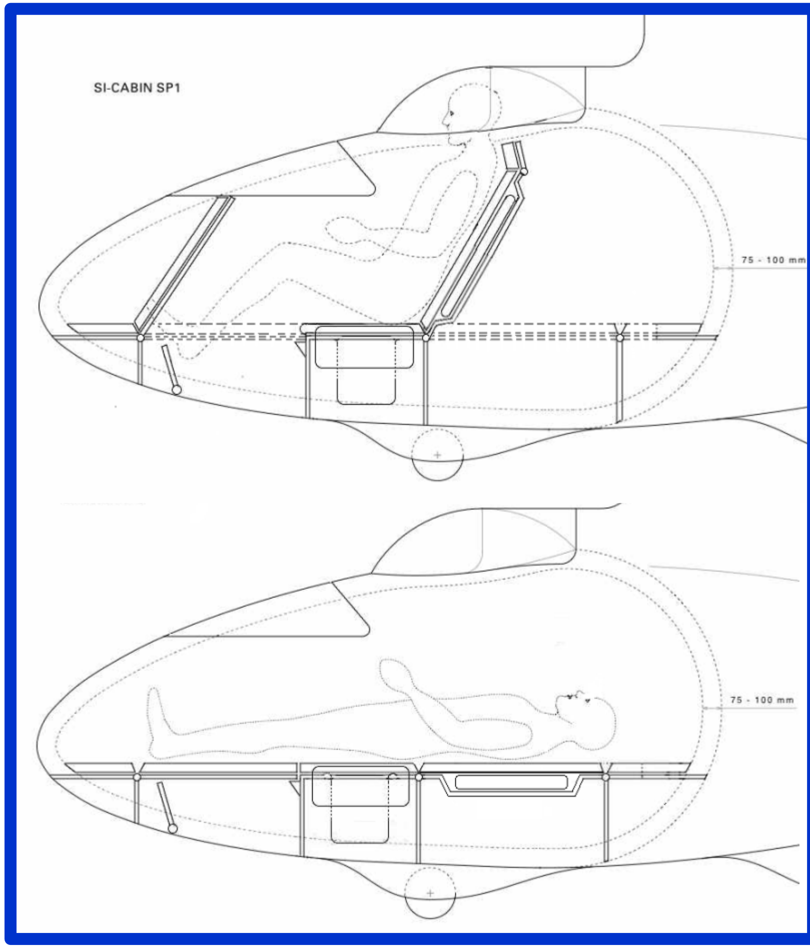
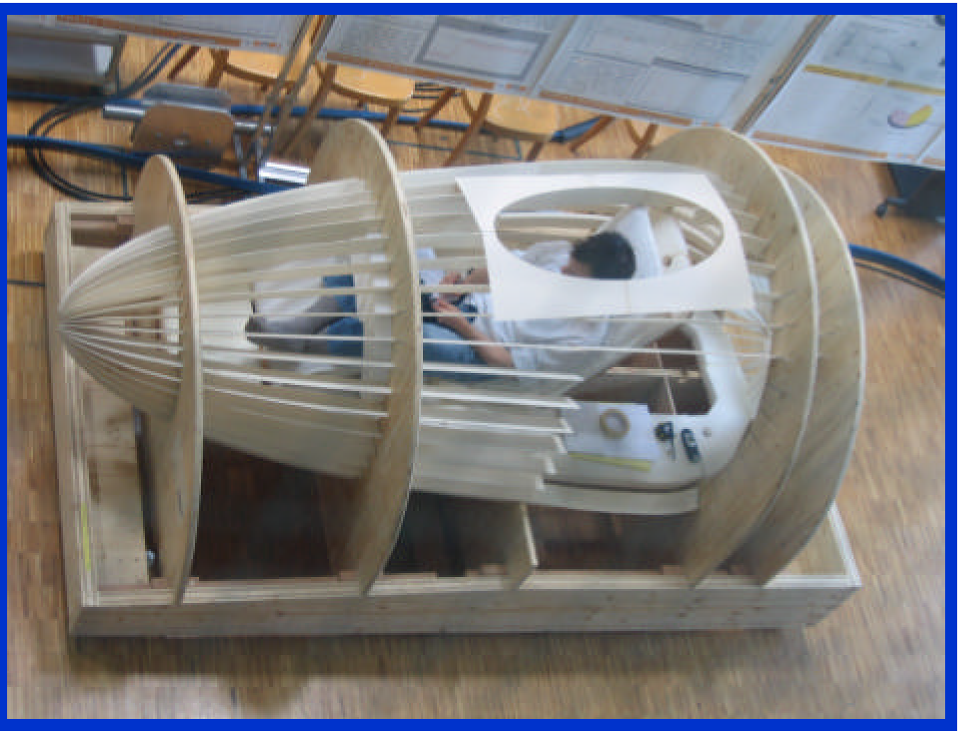
Solar Impulse, Cockpit Mock-up, Record Aircraft





Current design: Record Aircraft

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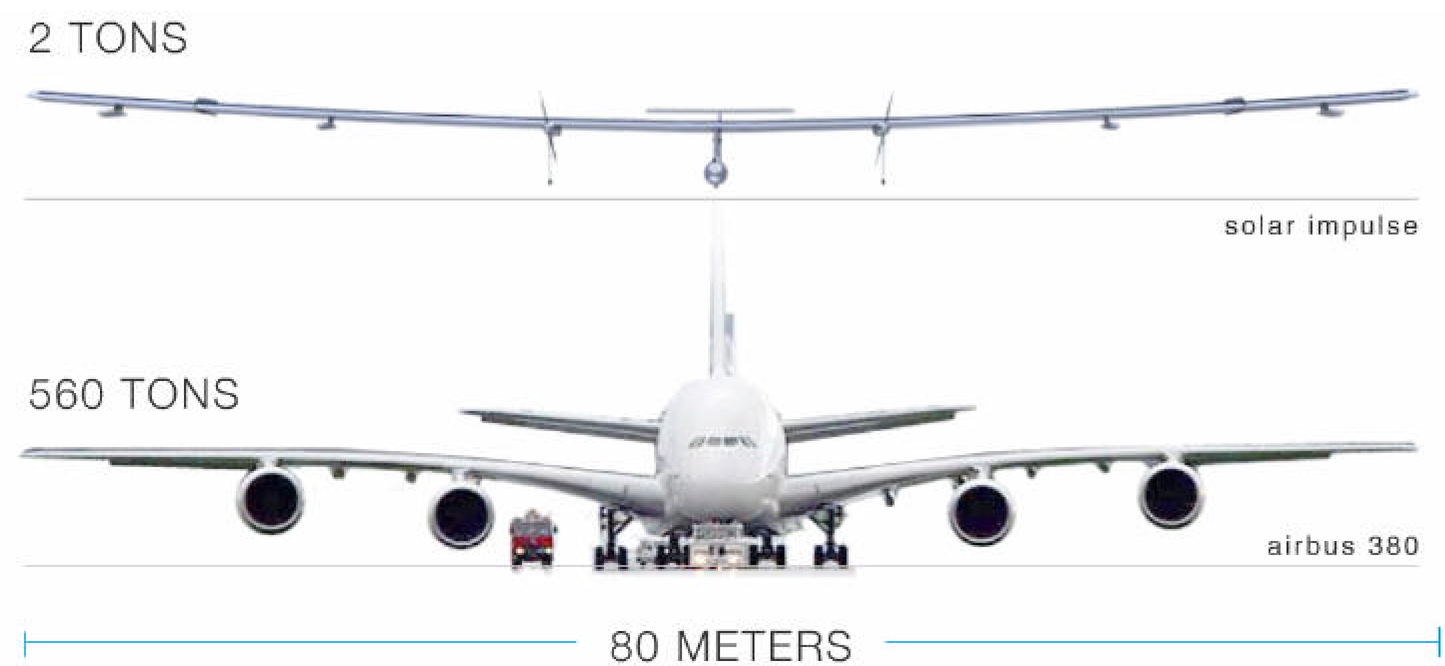

© Solar Impulse

Program Schedule

AROUND THE WORLD
WITH A SOLAR AIRPLANE

<u>It is a long term project:</u>

2003	Feasibility study at the EPFL de Lausanne in
2003	Announcement of challenge on 28 November
2004-2006	Concept Development
2007-2009	Design and manufacturing of a prototype,
2009, June	Unveiling of Prototype, initial test flights
2010	36 hour record flight
2009-2011	Design and Construction of the final airplane
2012	Missions of several days, crossing of the Atlantic and tentative tour of the world completing in five stages

Conclusions

AROUND THE WORLD
WITH A SOLAR AIRPLANE

The development of a manned solar powered aircraft capable of staying aloft for more than 24 hours is still a big challenge: It requires

- **an aircraft with very large physical dimensions, (area and wing span)**
- **Ultra light structural design with high stiffness**
- **Solar cells with very high efficiency (> 20%)**
- **Batteries with very high specific energy capacity (>200 Wh/kg)**
- **Very light and efficient electrical engine**
- **Minimum equipment mass and electrical consumption**

AROUND THE WOR
WITH A SOLAR AIR

With Solar Power around the world:

The Core Team

AROUND THE WORLD
WITH A SOLAR AIRPLANE

Program Founders

AROUND THE WORLD
WITH A SOLAR AIRPLANE

Main Partners

SOLVAY OMEGA Deutsche Bank

Official Partners

altran

Official Supporters

semper

Official Suppliers

VICTORINOX BKW SolarMax

Scientific and aeronautical partnerships

EPFL esa DASSAULT AVIATION

E N D