PRIVATE SUBORBITAL HUMAN SPACE FLIGHT & Rocket Propulsion Systems for Spaceplanes

ArianeGroup view on regulatory environment

J.Ph Dutheil, 02-04-2019
**SUB-ORBITAL REGULAR TRANSPORTER**

- **Twin turbofans for aeronautic phases** (compliant with EASA CS-E / CS-34 / CS-36)
- **Rocket propulsion used only for acceleration to 100 km**
- **Wing**: low drag at high Mach, good handling characteristics at low speed
- **Flight deck design**: mono-pilot, specific + business jet avionics
- **Design of most items based on aeronautic state-of-the-art (EASA CS-23 / CS-25)**
- **Attitude control in space by rocket thrusters**
- **Attitude control in space by rocket thrusters**
- **3 to 5 flights a week, from civil airport**

**Stages of Flight:**
- **Jet Engine phase**
- **Rocket Engine phase**
- **Ballistic phase**

**EMBRAER 135 Regional Jet**

**SpacePlane**
MARKET OVERVIEW: HUMAN COMMERCIAL SUBORBITAL SPACEFLIGHT

World market forecast
*(over 10 first years)*
*then, average 2.3 to 5.8 Bn €/year*

12 to 31 Bn €

4 to 10 Bn €

Spaceplane ADS/AG concept market share (1/3rd)

*(μ-gravity and science market: to be added)*

(Number of new passengers (per year) (extrapolated using S-Curve))

Scenario 5  Scenario 1

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Years after launch

Number of passengers
Opportunity of an intermediate market: Commercial human sub-orbital spaceflight
- Return on invest, paying back the assets (techno, products, infra): sales of products + maintenance
- Leveraging industrial partners capability and strength for leading future regular access to commercial space
SPACEPLANE R.P.S.* ON TECHNO MATURATION PATH TOWARD PROPULSION OF FUTURE VEHICLES:

* Rocket Propulsion System

= Space access maturity steps
= Aircraft propulsion fertilization

New Market accessible

Technological, Operational, Market access Capability Growth

Spaceplane techno. & regulation & operation

Sub-orbital access-to-space

Cryoplane fuel management & certification

Low emmission & post kerosene aircraft

Sub-Orbital Point-to-Point techno & regul & ops

High-Speed air breathing

High-Speed, low emmission transport

Orbital high flight-rate logistic market

Expendable rocket techno.
ARIANE GROUP DRIVER: SAFETY MATTERS FIRST

Manned-space safety level: not high enough

The future of human regular access to space relies on safe transport

Aeronautic-like safety level

Passenger safety first

Application for a certification, by independent safety authority

Access for the many, as paying passengers

No more access for the only paid & trained astronauts

Access best design rules.
FLIGHT ENVELOPE: MACH NUMBER VS. ALTITUDE

1 Space Ascent Gate
2 Space Descent Gate

Descent from apogee
Climb to apogee
Iso-pdyn (Pa)

Mach (-)

Altitude (km)

FL 600

Supersonic
FLIGHT OPERATIONS FROM CHANGI INTERNATIONAL AIRPORT

Scenario of daily departures addressed with CAG¹ & CAAS²

Aeronautic chart of Singapore air space

Changi airport of Singapore

Above FL 600 to space and back: need to manage non-interference with other users

¹ Changi Airport Group
² Civil Aviation Authority of Singapore
RPS & VEHICLE INFRASTRUCTURES
IMPLEMENTATION IN A REAL AIRPORT
Thank you!
SUPPORTING SLIDES
Number of studies on suborbital reusable vehicles (SRVs) markets have been published in the last 10 years

<table>
<thead>
<tr>
<th>Human spaceflight</th>
<th>Science &amp; Tech.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chosen data basis and edition year</strong></td>
<td><strong>Similar studies which were considered</strong></td>
</tr>
</tbody>
</table>
| Ipsos 2010 | • FUTRON 2002, 2006  
• TAURI 2012  
• IPSOS 2007 and 2010  
• ADIC 2012 | ▪ **Best survey methodology** (e.g., brochure given, qualitative interviews, definition of target customer groups, market growth and maturation)  
▪ **Largest sample size**, geographic coverage (worldwide)  
▪ **Ticket price evolution** considered in different scenarios |
| The Tauri Group 2012 | • ADIC 2012  
• NASA, INNO360 | ▪ **Thorough and robust** methodology  
▪ **Sound research**, e.g., interviews with 60 researchers, extensive database/publication search for research partners  
▪ Assumed **academic funding** by 50 governments and different scenarios modeled |
Market estimation methodology

Data needed to estimate market size and the drivers of demand were collected in two stages:

- **A qualitative stage**, including in-depth one hour interviews, were conducted among High Net Worth Individuals (HNWI) that had expressed interest in participating in a suborbital trip.
- **A quantitative stage** where around 2000 people representative of HNWI population were interviewed on line though a questionnaire.

To give reality to suborbital trips, a special marketing brochure was designed and used during qualitative and quantitative stages.

A first round of interviews was conducted in 2007. 1250 people were interviewed with the following split across countries:

- US: 400
- Japan: 200
- Germany: 150
- UK: 150
- France: 150
- Italy: 50
- Spain: 50

A second round of 600 interviews was conducted in 2010 (after financial crisis) in the following countries:

- China: 150
- Hong Kong: 150
- Singapore: 150
- Australia: 150

(Nota: In order to estimate the rest of the global market, particularly Latin America and Middle East, a conservative extrapolation from European Model was performed by Ipsos.)

A worldwide study

% HNWI share, 2012 (Source: CapGemini / Merrill Lynch)

- N.A: 29%
- E.U: 28%
- M.E: 4%
- Asia-Pacific (ex. Japan): 21%
- Japan: 12%
- L.A: 5%
- AFR: 1%
The distribution of the potential market over the time is represented by a Fisher-Pry curve with the following equation: 0.5 x ((1+hyperbolic tangent (a x (t-t0)))

The market was estimated with the parameters a=0.12 and t0=21 with corresponds to a 30-year maturity (conservative).

The S form of the Fisher-Pry curve best describes this type of market with a technological connotation.

We assume in our market study that suborbital flights are well marketed and that promotional campaigns are successful.

Out of a sense of prudence, the study considers that this experience will be done only once per household.

No growth of the HNWI population is considered (conservative)

Between 40 000 to 100 000 passengers at year 20
(in between 0.3-0.6% of 2015 HNWI\(^1\) households)

\(^1\) High Net Worth Individual
SPACEPLANE « ROCKET PROPULSION SYSTEM »

Rocket Engine ACE-42R (42 t thrust)
• Thrust Chamber > 40 cycles
• Turbo-Pump > 80 Cycles
• Gas Generator > 80 cycles

High Pressure Tanks > 480 cycles
Propellant Tanks > 480 cycles
Fluid control & Feeding system: xx cycles

Design-To-Safety
Design-To-total Cost
Design-To-Performance
Design-for-Budget
Design-for-Environment
DESIGN-TO-SAFETY / CERTIFICATION

(*) European Aviation Safety Agency

Set the acceptable level of risk

Certification rules identification / regulation

Industry to adapt engineering methods & organisation

Fail-Safe concept

Proba. Catastrophic failure $\leq 10^{-x}$
DESIGN-TO-SAFETY / CERTIFICATION

 Processes
 CS-23, CS-E, CS-APU

(*)

Design-to-Safety
Starting with "rules identification"

Merging 2 cultures

2,500 (core) rules

Guidelines

applicable as is

To be adapted

(*) Certification Specifications

Design Rules
System Engineer...
SPACEPLANE RISK REDUCTION: ROCKET PROPULSION ASPECTS

Oxygen/Methane reusable rocket Engine key elements tested at scale 1

PDM Turbo-Pump tested
PDM Gas-Generator tested
PDM Thrust-Chamber tested

900 mm

IHI
Realize your dreams

A Lox/Methane reusable Gas-Generator
> 2 MW power, down-rated regime tested (for throttability)
> 60 life cycles

A Lox/Methane reusable Thrust-Chamber:
30t thrust (sea level)
1m long
> 30 life cycles

100 bar pressure head
25% and 75% operation regime capability
> 60 life-cycles

2 MW power (turbine),
100 bar pressure-head
25% and 75% operation regime capability
> 60 life-cycles
SPACEPLANE RISK REDUCTION: SOME AIRCRAFT ASPECTS

Aerodynamique shape at high AoA*

Vehicle handling quality

Passengers environment & health

Man/Machine interface Single Pilot cockpit

Tests at ONERA & IMFL

Scales 1:10 & 1:4 models

hammock seats (patented)

Drop-test & model - Singapore

Certification approach (Vehicle and operations)

* Angle of Attack
** European Aviation Safety Agency
DESIGN TO ENVIRONMENT: PROJECT RISK REDUCTION

Thrust-Chamber test with Bio-Methane
FLIGHT ENVELOPE: MECHANICAL LOADS - OPERATIONAL LOAD FACTOR

- RPS cut-off
- Ascent
- Descent
- RPS ignition

Rocket Propulsion System
arianeGroup
MARKET OVERVIEW: SPACE TOURISM LEADERS

“Space tourism is the first step toward millions of people living and working in space”
Jeff Bezos

"I want to die on Mars,"
Elon Musk

“It's incredible to think only 450 people have ever been into space”
Richard Branson

“Why should Europe be spectator? Rather enter Aerospace History!”

ArianeGroup + Aircraft partner = full spectrum of competences to tackle complex innovative project