



The Known Unknowns of Rocket Launch: Safety and Reliability Assessment

British Computer Society Edinburgh presentation

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SKYRORA: FROM SCOTLAND TO SPACE

MISSION:

- Earth Observation positively impacts Sustainable Development Goals;
- The UK needs its own launch capability in order to fully realise the benefits the space sector can bring. Skyrora is the solution.

AMBITION:

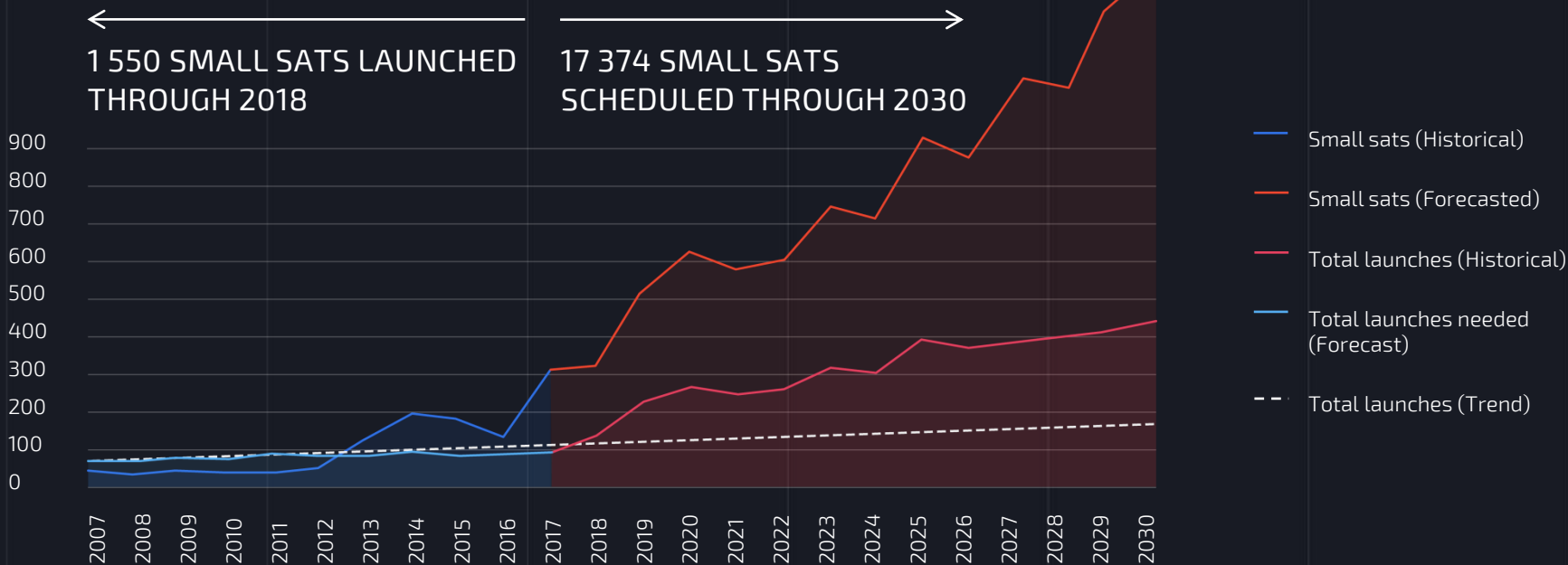
- Skyrora will connect world changing companies with low-cost access to space;

HOW:

- implementing a business plan incorporating iterations and milestones;
- starting small and building the value chain;
- creating sustainable partnerships – universities and companies- across the space sector;
- collaborating as an industry to help fashion the regulatory environment;
- extensive STEM initiatives to create the employees of tomorrow;
- develop cost-based (justified) value offer for UK's access to LEO;



LAUNCH DEMAND VS SMALL SATELLITE DEMAND*



*Less than 33% of demand can be met by existing rideshare capacity

Source: Euroconsult, 2017
Internal estimations

EUROPEAN SMALL SATELLITE MARKET



18%

of the world's small satellites are manufactured in Europe, of which over half are from the UK

2000+

satellites to be launched from Europe during 2023–2030

76%

in the <315 Kg weight class (Skyrora's addressable niche)

£5 BN

cumulative addressable European launch market for 2023–2030

Source: 2018 Frost & Sullivan
for UKSA
Seraphim Fund research

OPPORTUNITY

THERE ARE CURRENTLY NO
OPERATIONAL SMALL SATELLITE
LAUNCHERS IN EUROPE

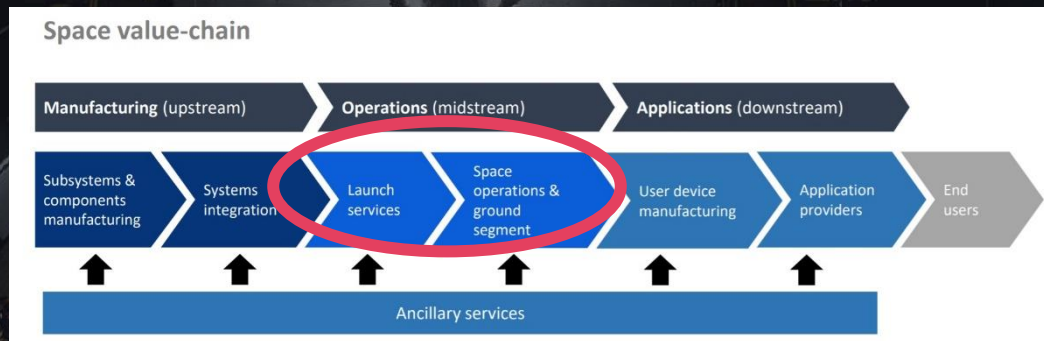
Current rideshare model is broken

No guarantee for most efficient deployment orbit

High price per kilo

Regulations & bureaucracy

EVERY DAY VITAL
TECH RESEARCH IS
PUT ON HOLD WHILE
SATELLITES CONTINUE
TO JOIN THE QUEUE



SKYRORA AS A SOLUTION



SKYRORA WILL ENSURE THE WORLD-CHANGING BENEFITS OF SPACE ARE REALIZED HERE ON EARTH

New Space enterprise manufacturing responsive, versatile and dedicated 3-stage satellite launch vehicles to make space more accessible

Aim to deploy payloads of 315kg to Polar and Sun-Synchronous orbits with launches from Scotland

British space heritage, reinforced by R&D centers in Ukraine & Slovakia

All-in-one service and associated support provider

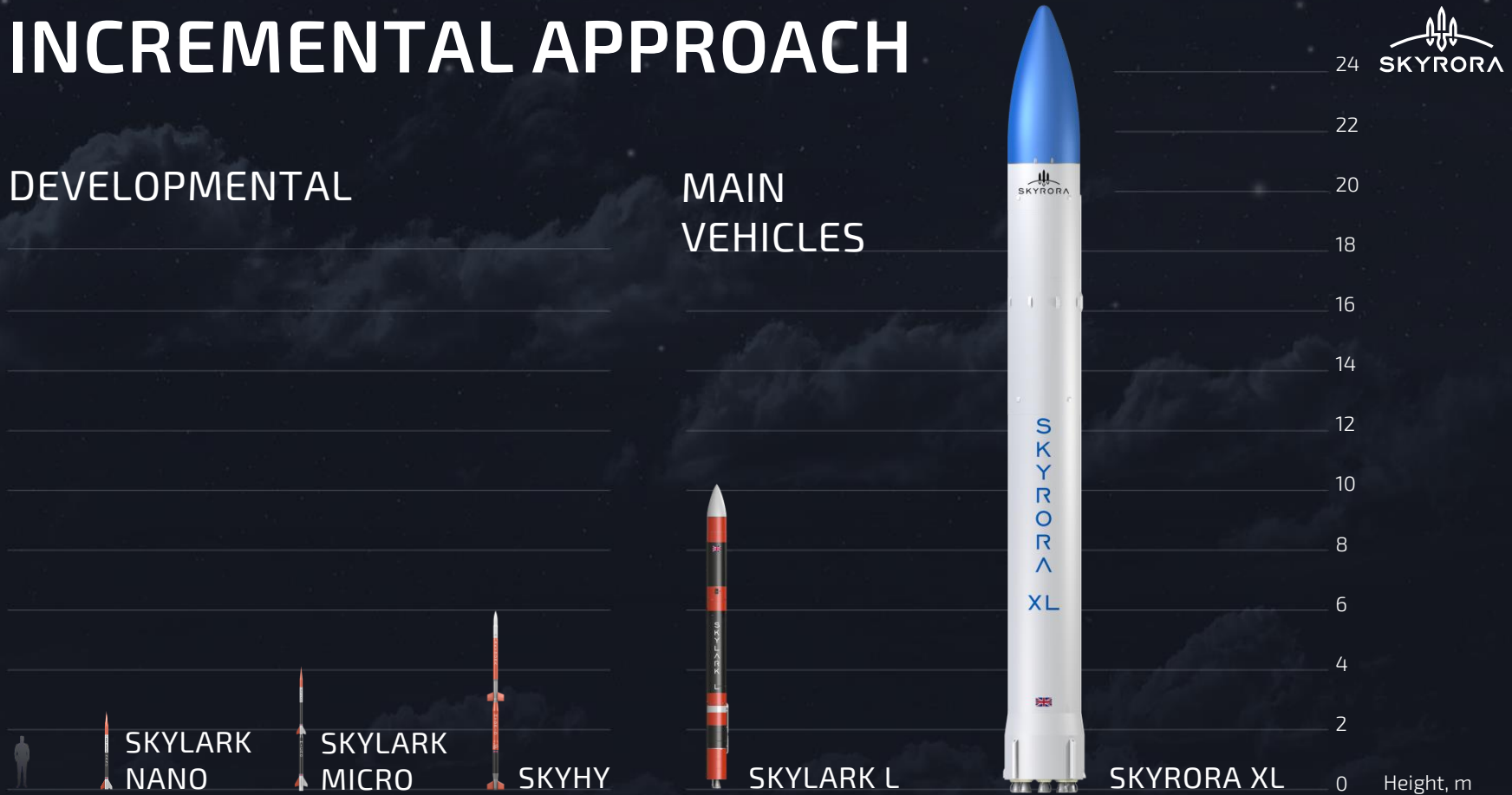


INCREMENTAL APPROACH



DEVELOPMENTAL

MAIN
VEHICLES



PROGRESS

SKYLARK NANO

Proof of reusability (two launches:
2018, 2019)



SKYLARK MICRO

Completed in March 2019
Practice safe launch to 30 km
OFCOM: license granted



HYBRID ROCKET SKYHY

Completed in May 2019



SKYLARK MICRO

OVERVIEW



CHARACTERISTICS

LENGTH 3324mm

DIAMETER
FIRST STAGE 102mm
SECOND STAGE 75mm

LIFT-OFF MASS 32kg

PROPELLANT HTPB

THRUST
FIRST STAGE 1561N
SECOND STAGE 838N

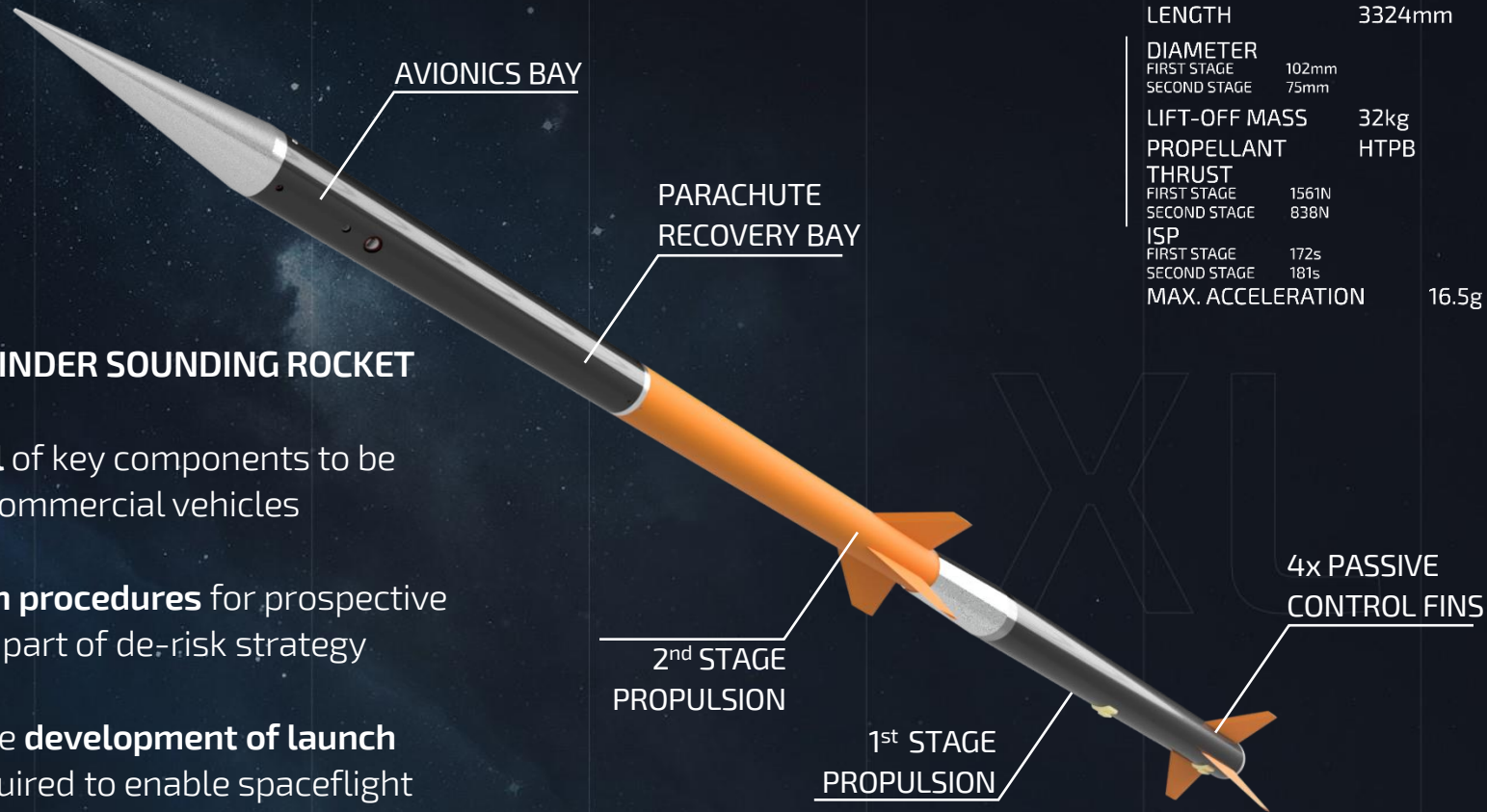
ISP
FIRST STAGE 172s
SECOND STAGE 181s

MAX. ACCELERATION 16.5g

SKYRORA'S PATHFINDER SOUNDING ROCKET

KEY OBJECTIVES

- **Raise TRL level** of key components to be integrated on commercial vehicles
- **Develop launch procedures** for prospective launch sites as part of de-risk strategy
- Accelerating the **development of launch legislature** required to enable spaceflight from new countries





2nd STAGE APOGEE
30,000m

SKYLARK MICRO

FLIGHT TRAJECTORY

AZIMUTH 10° wrt T. North
PITCH 82°

DOWNRANGE DIST. 18km
MAX. ALTITUDE 30km

MAX. SPEED MACH 4

1ST STAGE APOGEE
6km



SKYLARK MICRO

GROUND OPERATIONS

FLIGHT PREDICTION AND LAUNCH CONTROL

- Our SRMC (Sounding Rocket Mission Control) is the centralized hub for all communications and launch operations

Radiosonde Meteorological Balloon operations

- Meteorological weather balloons provide accurate weather information for trajectory analysis and enable go/no go for launch decision making



SKYRORA
SOUNDING ROCKET MISSION CONTROL

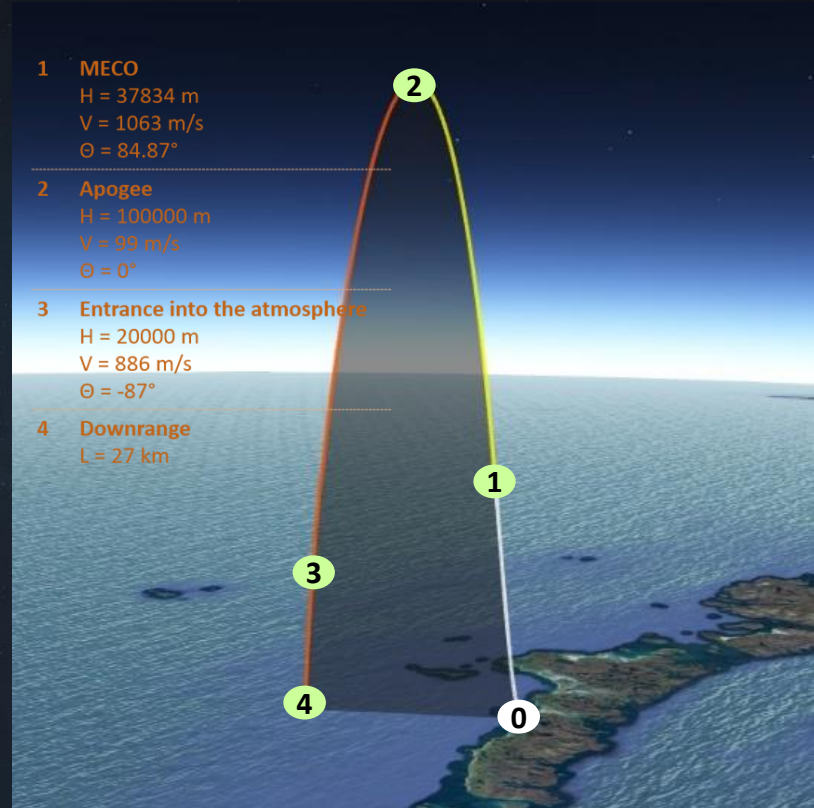
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SKYLARK-L

Skyrora Skylark-L is a one-stage sub-orbital launch vehicle designed to launch a 100 kg payload to approximately 100km

The vehicle is powered by 30kN engine, with liquid propellants pressure fed

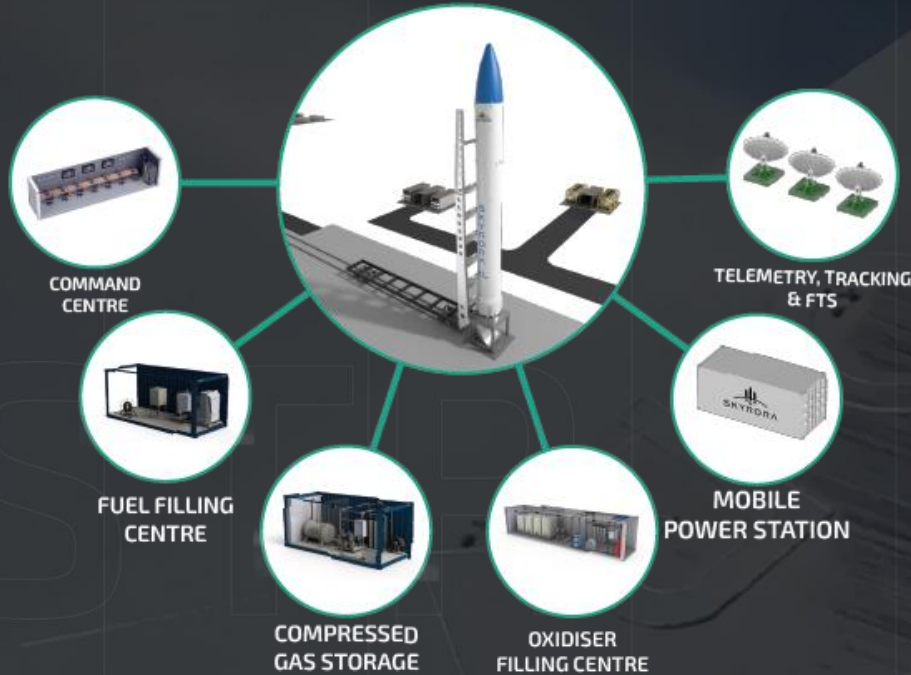
| Name | Parameters |
|--|-------------------------------|
| Lift-off mass | 2 498 kg |
| Payload mass, kg | 100 kg |
| Propellants: - oxidizer - fuel | hydrogen peroxide kerosene |
| Type of main engine | LPRE |
| Propellant fed system | Pressure fed system |
| Nominal thrust of main engine: - above sea level - in vacuum | 3 058 N 3 645 N |
| Nominal specific impulse: - above sea level - in vacuum | 227.0 s 270.5 s |
| Engine operation time | 113 s |
| Max g-load | up to 4 |





Modular Launch Complex

MODULAR LAUNCH COMPLEX



SKYRORA XL

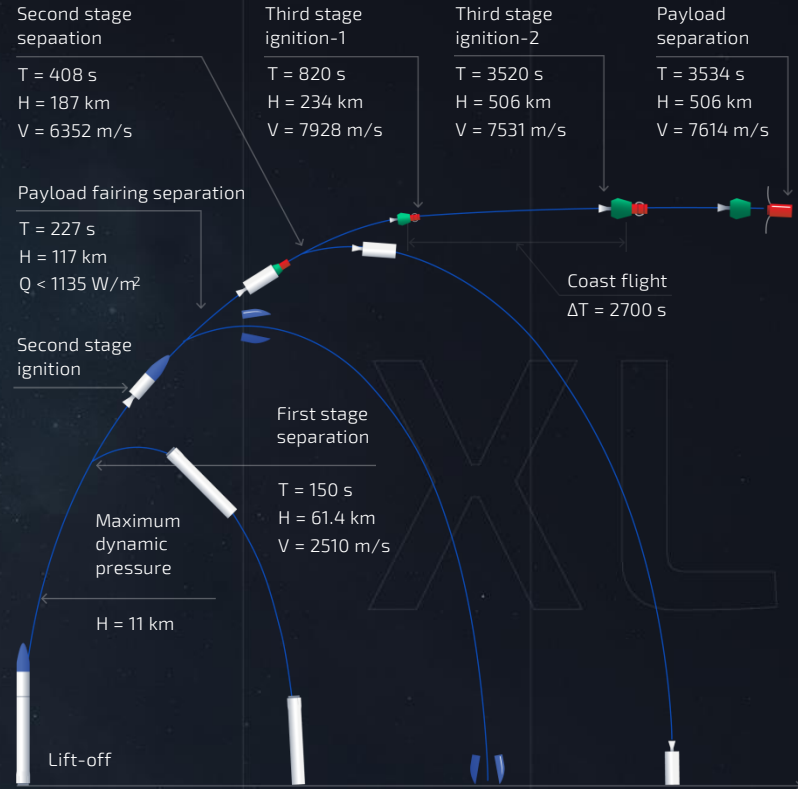
Skyrora XL is a three-stage orbital launch vehicle designed to launch a 315 kg payload to Polar and Sun-synchronous orbits

Engines are powered by advanced turbopump techniques and liquid propellants

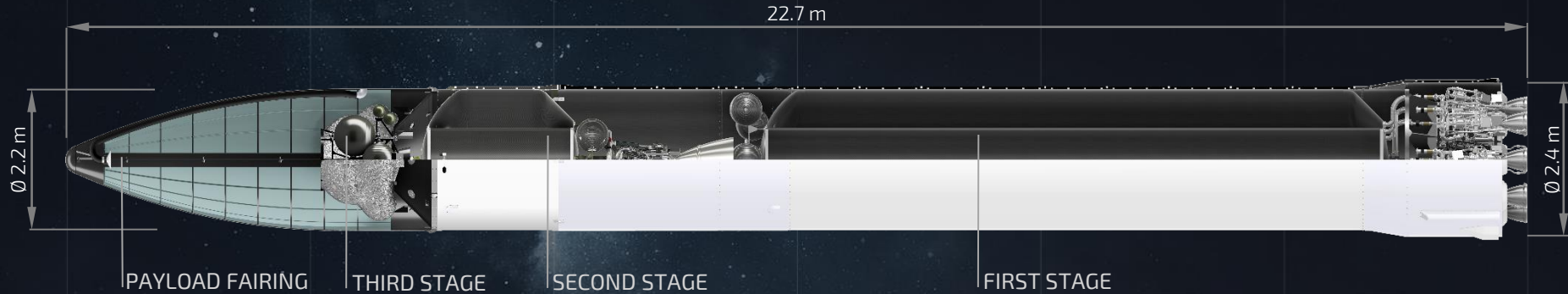
REIGNITABLE THIRD STAGE

Thrust (in vacuum): 3.5 kN

Exhaust velocity (in vacuum): 3,004 m/s



SKYRORA XL



ENVIRONMENTAL CONSCIOUSNESS

Our proprietary synthetic fuel from recyclable plastic enables Skyrora XL to generate less carbon foot-print than Boeing 747.

No space debris

LOW G-FORCE

Our propulsion combination makes payload's journey to space weather tolerant, reliable and with lowest stress possible (5G instead of 10G)

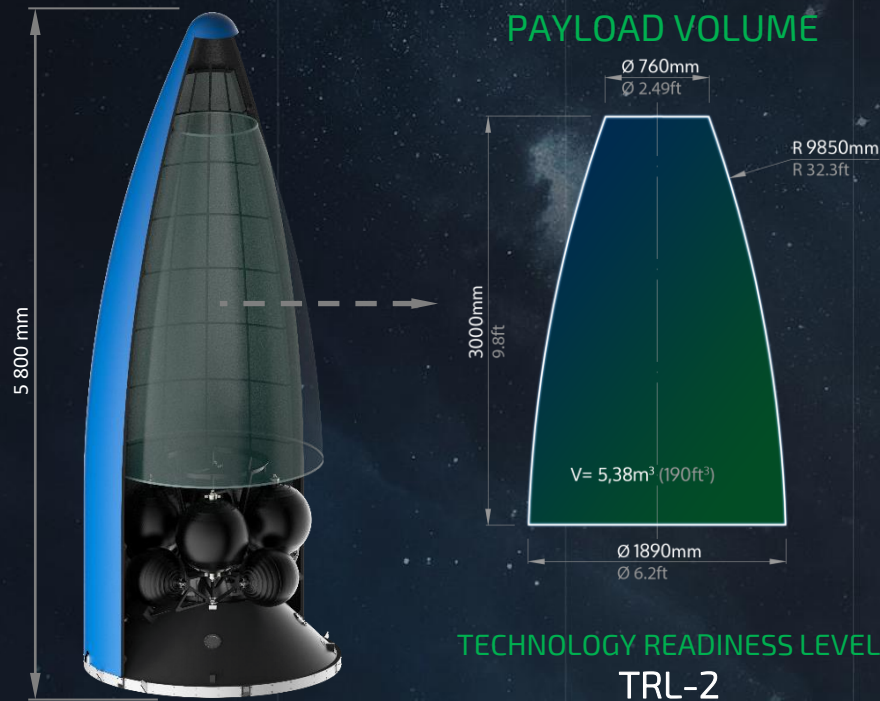
DIRECT ORBIT INSERTION

Re-ignitable 3rd stage engine enables precise bespoke and highly effective orbits. This service currently unavailable from vast majority of competitors

COST EFFICIENCY

Unique choice of non-cryogenic fuel makes all infrastructure and launch management much simpler, cheaper and more stable

SKYRORA XL PAYLOAD ACCOMMODATION



Payload accommodation scenarios available:

Single (primary only)

Primary payload and secondary payloads (including CubeSats)

ENVIRONMENT

Inside temperature during pre-launch operations
10-28°C

Heat flow from fairing during flight
no more than 500 W/m²

Free molecular flow
no more than 500 W/m²

Humidity no more than 65%

Cleanliness TBD

Max g-force up to 5

MATERIALS and TECHNOLOGY

| | | |
|--------------------------|---------------------|---------------------------|
| | case unit structure | |
| carbon fiber | | prepreg molding |
| | Brackets, fittings | |
| aluminum alloy, steel | | milling, turning, bending |

SKYRORA XL THIRD STAGE

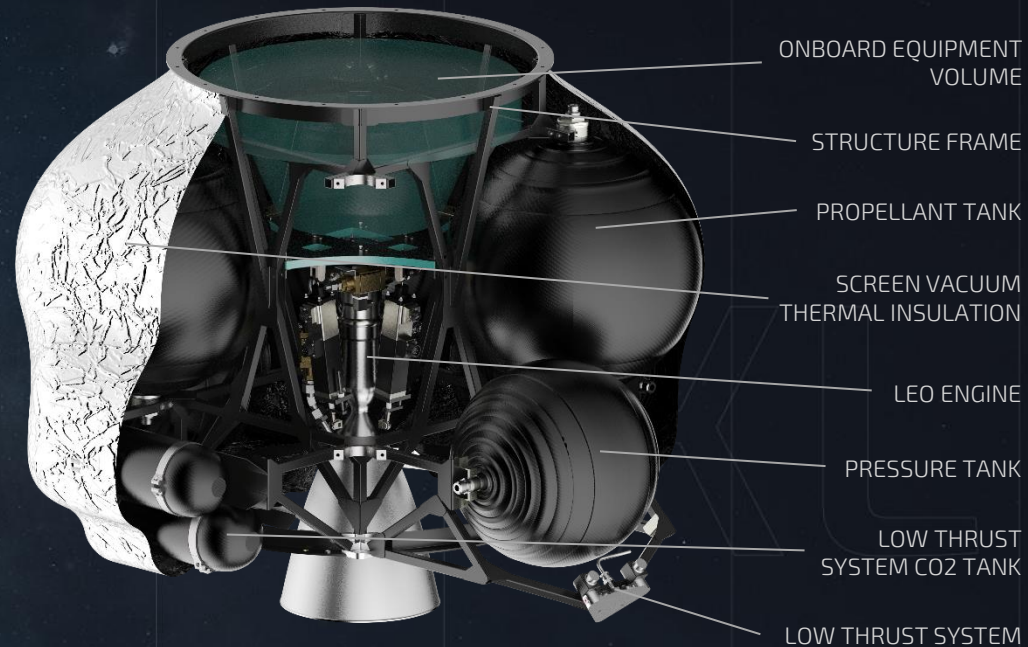


MAIN CHARACTERISTICS

| | |
|----------------------------|----------------------|
| Dry mass | 314 kg |
| Loading mass | 590 kg |
| Propellant: | |
| - oxidizer | Hydrogen peroxide |
| - fuel | Kerosene, Ecosene |
| Propellant feed system | Pressure-fed |
| Engine thrust in a vacuum | 3500 N |
| Numbers of engine ignition | Up to 11 |
| Attitude control | Electro actuator TVC |

MATERIALS and TECHNOLOGY

| | |
|---|----------------------------|
| case unit structure | |
| carbon fiber | prepreg molding |
| Pressure vessel, propellant tank (load shell) | |
| carbon fiber | filament winding |
| Pressure vessel, propellant tank (liner) | |
| aluminum alloy | stamping, turning, welding |
| Brackets, fittings | |
| aluminum alloy, steel | milling, turning, bending |
| Pipes | |
| aluminum alloy, steel | bending, welding |

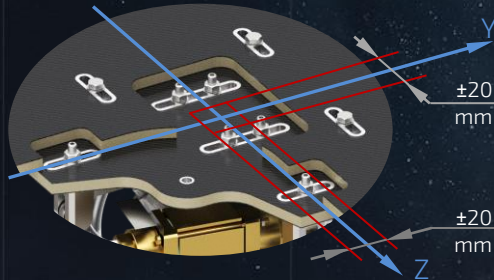


TECHNOLOGY READINESS LEVEL TRL-3
READY TO STATIC FIRE TEST Q4 2020

THIRD STAGE LEO ENGINE



POSITION ADJUSTMENT



SPECIFICATION

Type of propulsion system
LRE with pressure fed system

Propellant - fuel kerosene

Propellant - oxidizer hydrogen peroxide

Thrust at sea level
3.5 kN

Specific impulse at sea level
2 085 m/s

Specific impulse in vacuum
3 004 m/s



MATERIALS and TECHNOLOGY

| | |
|--------------------------------|--|
| Thrust chamber | |
| Inconel 718 ASI 321 | DMLS vacuum brazing TIG welding. |
| Gimbal | |
| Aluminum alloy | 5 axial milling |
| Engine interface platform | |
| Aluminum alloy Carbon fiber | 3 axial milling prepreg molding |
| Brackets, fittings and pips | |
| Aluminum alloy ASI 321 | 3 axial milling TIG welding |

In 2020: 40 fire tests of 3 combustion chambers have been conducted with total operating time around 20 min

TECHNOLOGY READINESS LEVEL TRL-6

SPACE TUG



A space tug is an innovative piece of technology that can provide space services to satellites in orbit and future orbital spacecrafts.

The space tug is designed to be compatible with both the upper stage of the launch vehicle and payload components to enable a partner launch vehicle.

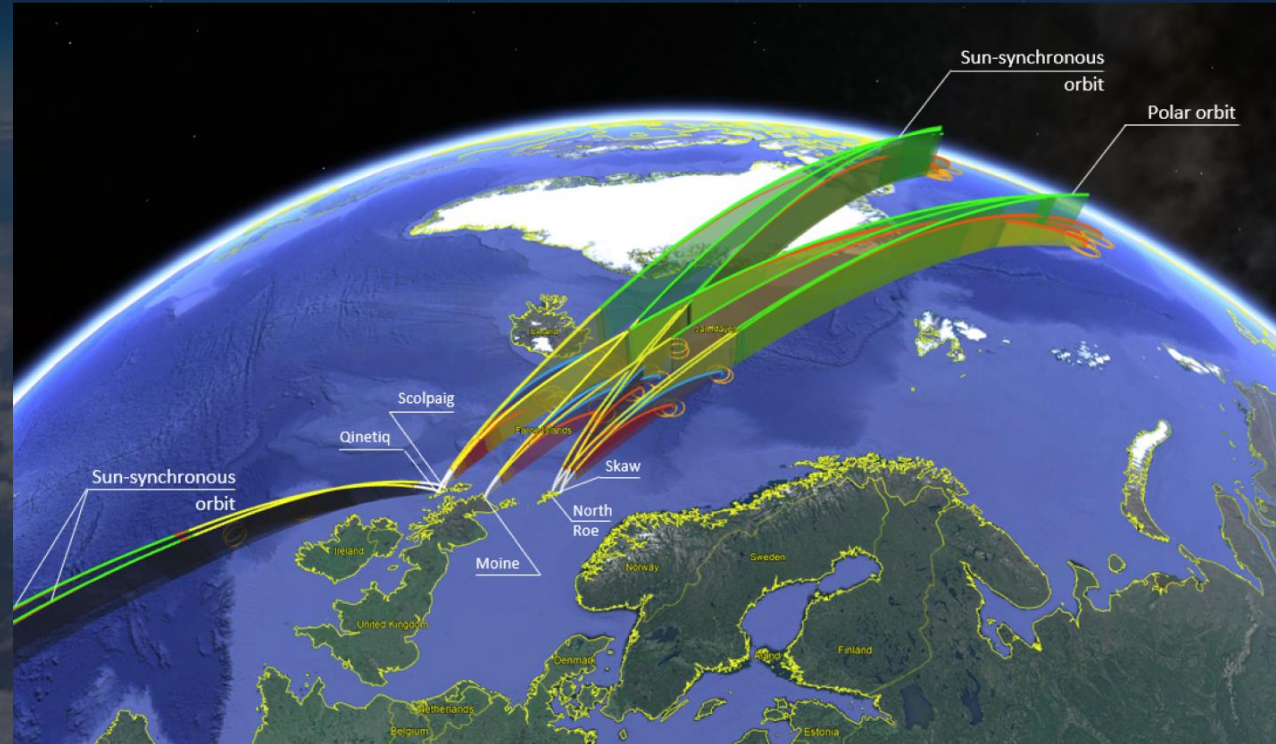
The main functionalities of the space tug include:

- deploying payloads into different orbits and altitudes;
- correcting satellite or spacecraft orbit;
- de-orbiting space debris or transferring space debris to disposal orbit;
- refueling satellites or spacecrafts

VERTICAL SPACEPORTS SCOTLAND



Falcon 1, SpaceX



ECOSENE. ECO FUEL



Ecosene is innovative kerosene made of waste plastics and upgraded to be used as rocket fuel.

Using Ecosene over traditional Kerosene for 16 launches per year saves up to 400 tonnes of unrecyclable plastic every year

Metric tonnes of plastic recycled per year **400K+**



53X

Lorries per year

Successful test firing have been held for 350 kg (Leo) to compare kerosene and Ecosene. Result: Ecosene is 1% better than kerosene by its energy characteristics



ECOSENE CLEAN TECH AWARDS:


Go:Tech Awards 2019
Green Apple Award 2019
Net Zero Energy Pitch 2019
Scotland Business Award



COMPETITION

OUR KEY COMPETITIVE ADVANTAGES ARE:

- Re-ignitable 3rd stage
- Wide weather tolerance
- Low G-force, less stress on payloads
- Reliability, simple maintenance
- Privately owned modular spaceport
- Eco fuel
- Cost of talent



| Launch Vehicle | Skyrora XL | Prime | Miura 5 | Electron | LauncherOne |
|------------------|--------------|-------------|--------------|--------------|--------------|
| Founded | 2017 | 2015 | 2011 | 2006 | 2017 |
| Price/kg | £30k | NA | £28k | £46k | £33k |
| Mission revenue | £9.5m | NA | £8.4m | £9m | £9.9m |
| Payload mass, kg | 315 | 220 | 300 | 125 | 300 |
| Altitude, km | 500 | 500 | 400 | 500 | 500 |
| Readiness stage | Planned | Planned | Planned | Operational | Planned |
| Fuel | Kerosene/HTP | Bio-LPG/LOX | Kerosene/LOX | Kerosene/LOX | Kerosene/LOX |
| Stage / engine | 3 | 2 | 3 | 2+kickstage | 2 |

SKYRORA IS ON TRACK TO LEAD THE EUROPEAN SPACE RACE

BY 2030 SKYRORA will:

- Be a **World Champion** in Environmental Spaceflight (UK);
- Extracted **3000 tonnes** of unrecyclable plastic waste from the environment (landfill/oceans);
- fuelling **119** individual missions to LEO;
- delivering **3500** individual satellites into LEO;
- transforming **Environmental Management Systems** contributing to the achievement **70% of UN Sustainable Development Goals**;
- supporting **50 PhD** Earth Observation research projects;
- creating **300+ jobs** itself with not less than **30 apprenticeships**;
- **106m** in total launch related revenues, **22% CAGR** (profit)

By championing the concept of sustainable and responsible space utilisation from EU we will unlock a New Space Tech Revolution

SCOTLAND is leading SPACE in:

Creation of SCOTTISH SPACE LEADERSHIP COUNCIL – Business platform;

Satellite manufacture both quantity – demand for launch services;

SPACE DATA – Universities lead – St. Andrews, Edinburgh, Strathclyde;

Advanced Manufacturing – NMIS

Spaceport development – infrastructure – Spaceport working group within SSLC;

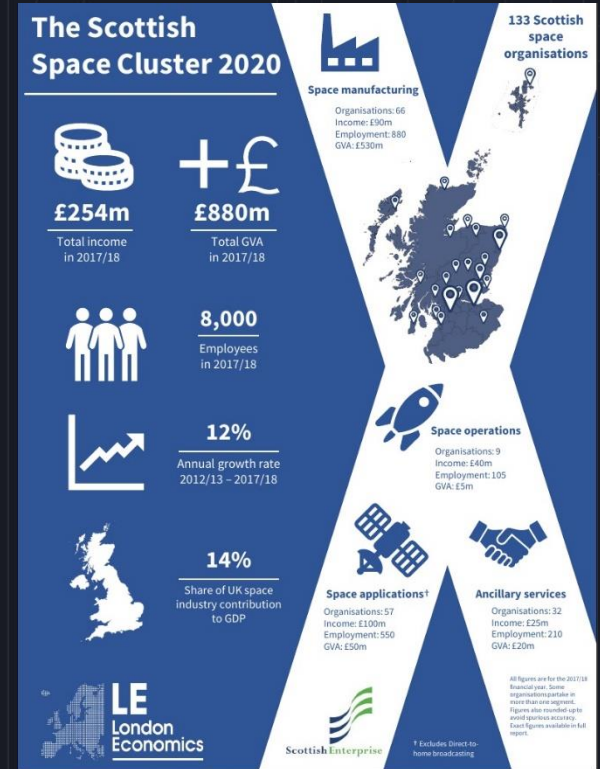
Rallying industry into input into legislation;

Environmental thought leadership for Space - society deliverable;

SPACE VALUE CHAIN fully represented

Beginning to reap the economic rewards of localizing supply chain- demand for engineering capabilities to support – STEM;

Alignment with adjacent industry- Aerospace, Marine;



THANK YOU!


Forbes

EDITOR'S PICK | 1 558 views | Aug 8, 2019, 7:00 am

Skyrora Reveals Launch Of Second Private Rocket From U.K. Soil

Jonathan O'Callaghan Contributor

Science
Jonathan covers commercial spaceflight, space exploration, and astrophysics



The launch took place last month. SKYRORA


Scottish launch company Skyrora says it successfully completed its second rocket test launch last month – as it moves towards a first flight to orbit from U.K. soil in 2022.

In a statement, the company headquartered in Edinburgh said it launched its two-meter-long Skylark Nano II rocket from Kildermorie Estate, Ross-shire in northern Scotland at just before 10 A.M. local time on Wednesday, July 10. The

TE

Launch startup Skyrora successfully tests 3D-printed rocket engines powered by plastic waste

Darrell Etherington
@etherington / 3:35 pm EET • February 3, 2020



Rocket launch startup **Skyrora**, an Edinburgh-based company that's developing a new launch vehicle for small satellites, has successfully tested its new rocket engines in their first stationary ground-firings, a huge step on the way toward developing their launch vehicle. Skyrora's rocket engines are novel not only in their use of 3D printing, but also because the fuel that powers them is

BBC NEWS

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Science & Environment

Lift-off for Scotland: Sutherland to host first UK spaceport

By Jonathan Amos
BBC Science Correspondent

16 July 2018



Farnborough Airshow

PERFECT CIRCLE

Artwork: This is what a Scottish spaceport could look like in the early 2020s

A remote, boggy stretch of land on the north coast of Scotland is set to become the UK's first spaceport.

The A'Mhoine Peninsula in Sutherland has been chosen as the most suitable place from which to

Members Area

UKSPACE

Scottish space firm Skyrora celebrates successful rocket engine testing

July 26th, 2019



26 July 2019 – Skyrora has successfully carried out testing on a fully 3D-printed, commercial rocket engine for the first time ever in the UK.

Edinburgh-based Skyrora used its base in Cornwall to carry out engine checks on its XL rocket, the firm's main orbital launch vehicle.

The engine boasts stop-start technology,

Forbes

1 831 views | Jul 26, 2019, 8:51 am

Scottish Launch Startup Skyrora Tests Rocket Engine That Could Reach Orbit From The U.K. In 2022

Jonathan O'Callaghan Contributor

Science
Jonathan covers commercial spaceflight, space exploration, and astrophysics



An image from the test conducted today. SKYRORA

Scotland-based startup Skyrora, which hopes to become one of several commercial companies to launch rockets from the U.K., says it has successfully tested a rocket engine that it will use on orbital launches beginning in 2022.

The company tested the engine called Leo for the first time in secret at Spaceport Cornwall in Newquay on Wednesday, July 24, successfully firing it for 30 seconds. It then conducted a

