The Known Unknowns of Rocket Launch: Safety and Reliability Assessment

British Computer Society Edinburgh presentation

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SKYRORA

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.

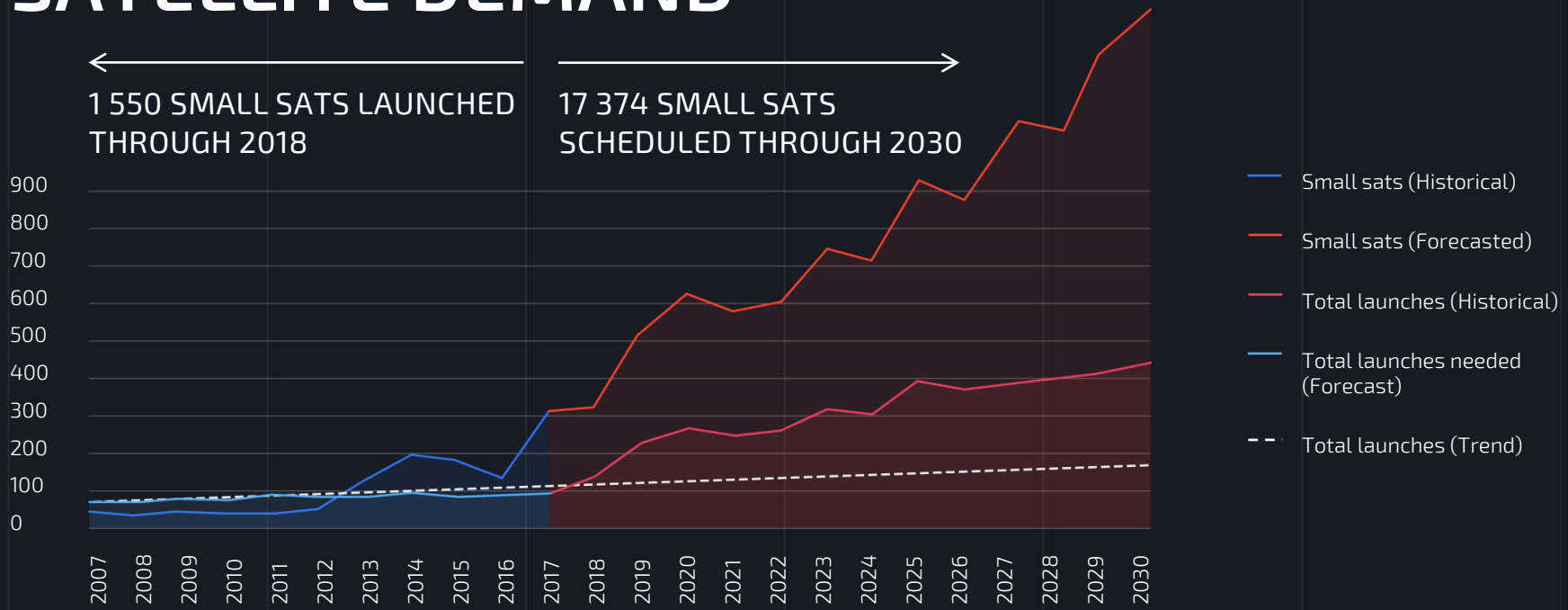
AMBITION:

- 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

SKYRORA

THERE ARE CURRENTLY NO OPERATIONAL SMALL SATELLITE LAUNCHERS IN EUROPE

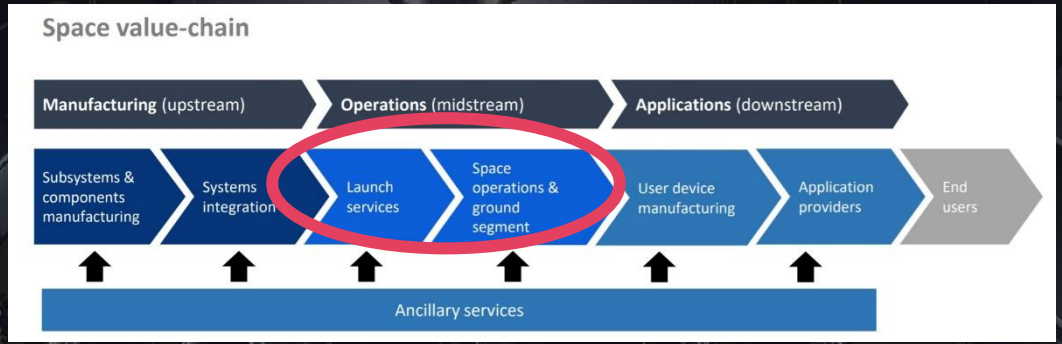
Current rideshare model is broken

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

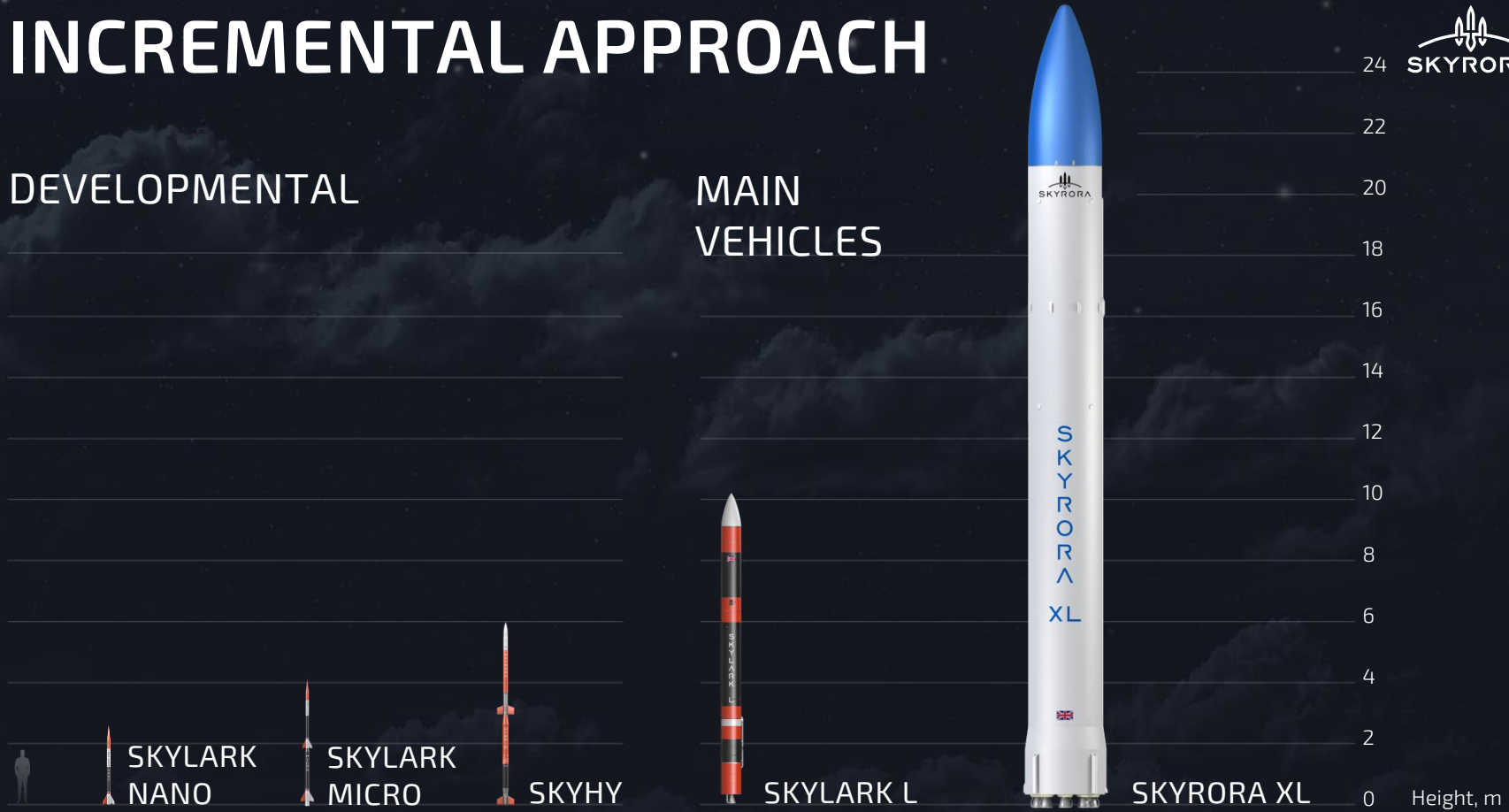
All-in-one service and associated support provider

INCREMENTAL APPROACH

SKYRORA

DEVELOPMENTAL

MAIN VEHICLES



SKYLARK NANO

SKYLARK MICRO

SKYHY

SKYLARK L

SKYRORA XL

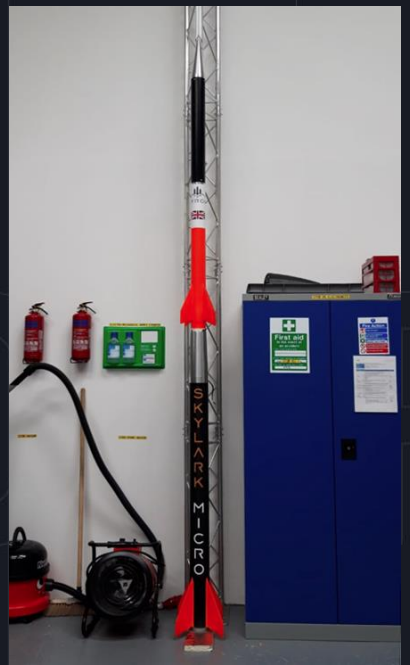
PROGRESS

SKYLARK NANO

Proof of reusability (two launches: 2018, 2019)

SKYLARK MICRO

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

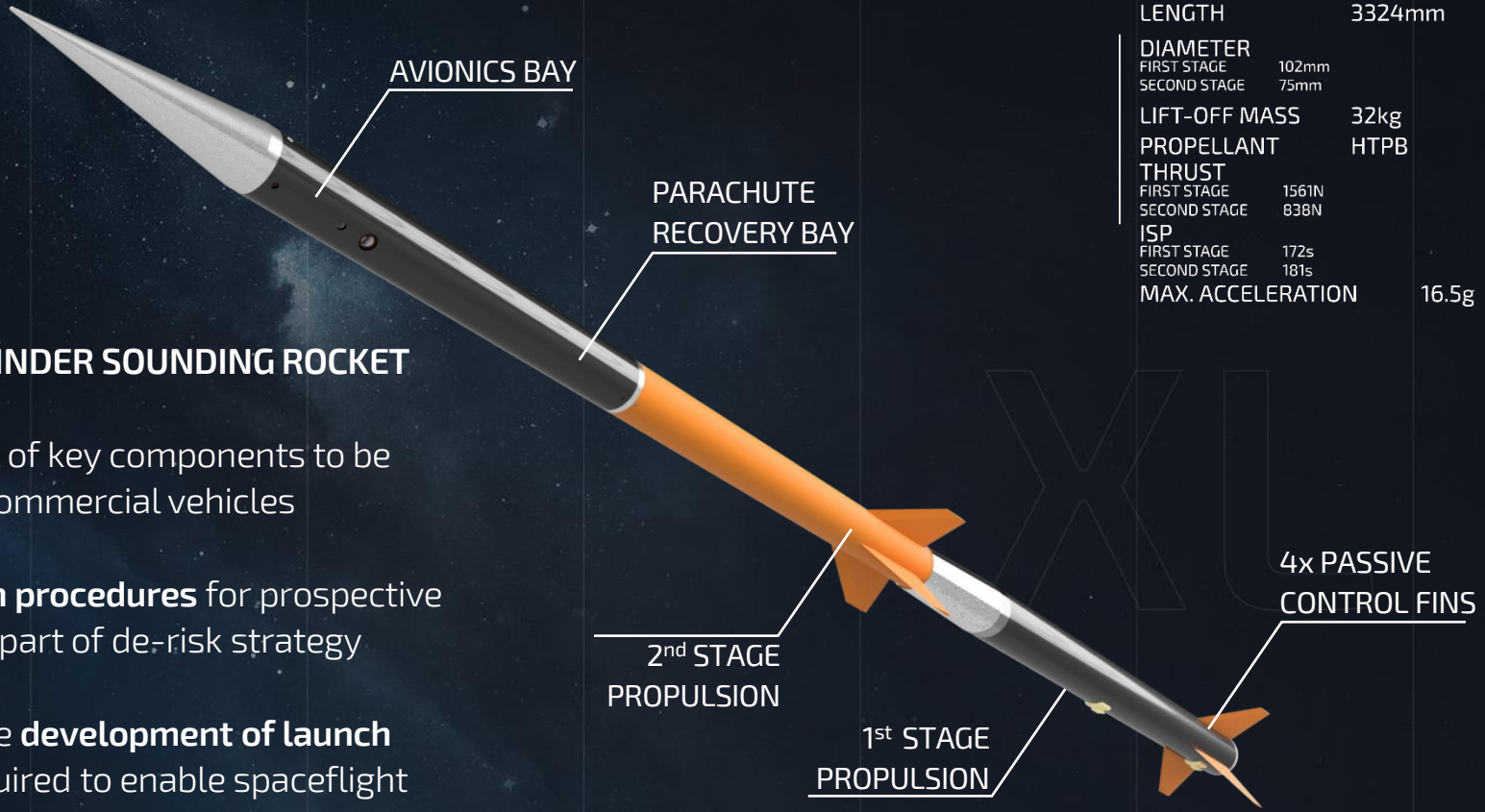


HYBRID ROCKET SKYHY

Completed in May 2019

SKYLARK MICRO
OVERVIEW

SKYRORA



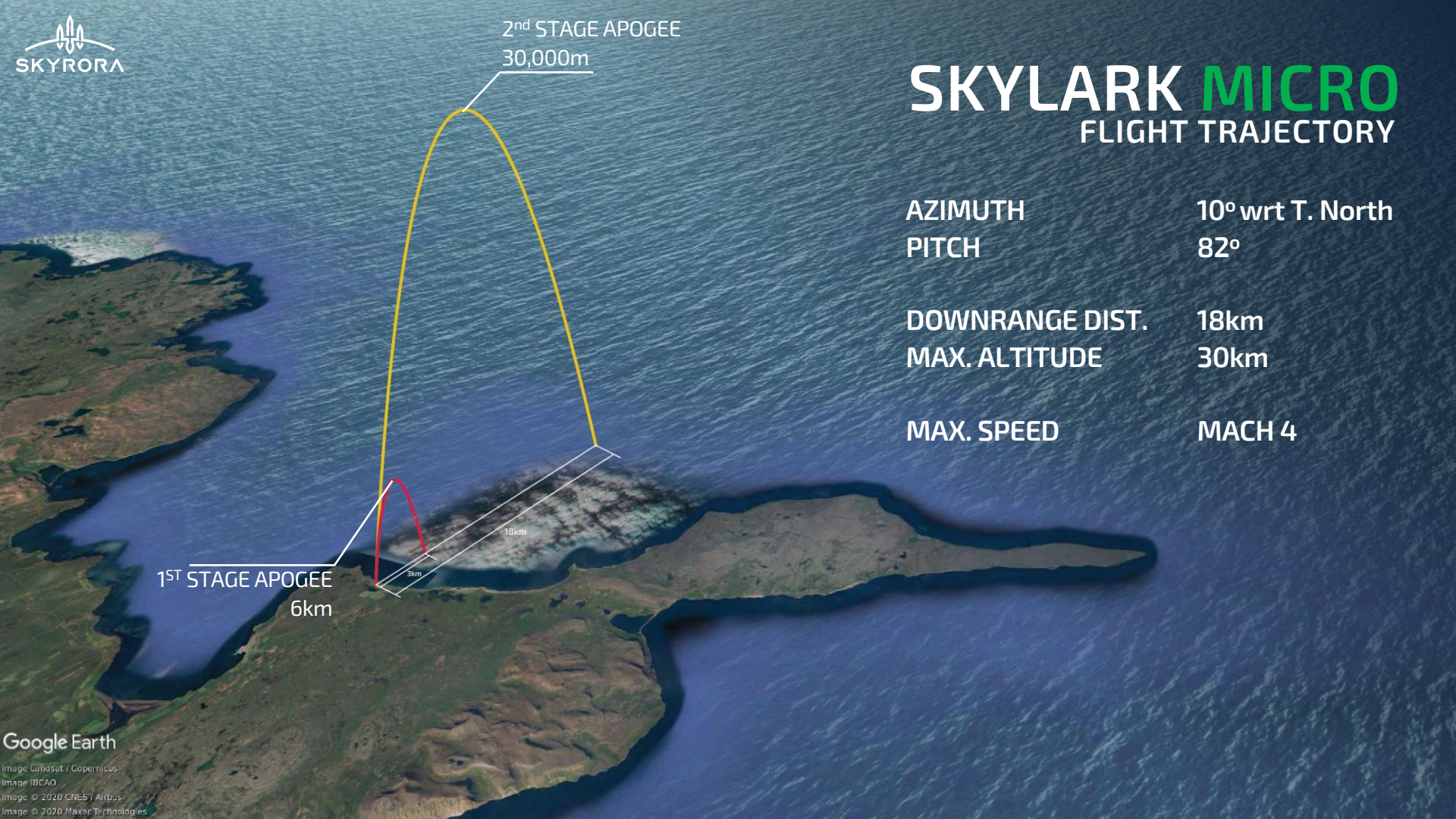
CHARACTERISTICS

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



SKYLARK MICRO

FLIGHT TRAJECTORY

AZIMUTH	10° wrt T. North
PITCH	82°
DOWNRANGE DIST.	18km
MAX. ALTITUDE	30km
MAX. SPEED	MACH 4

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

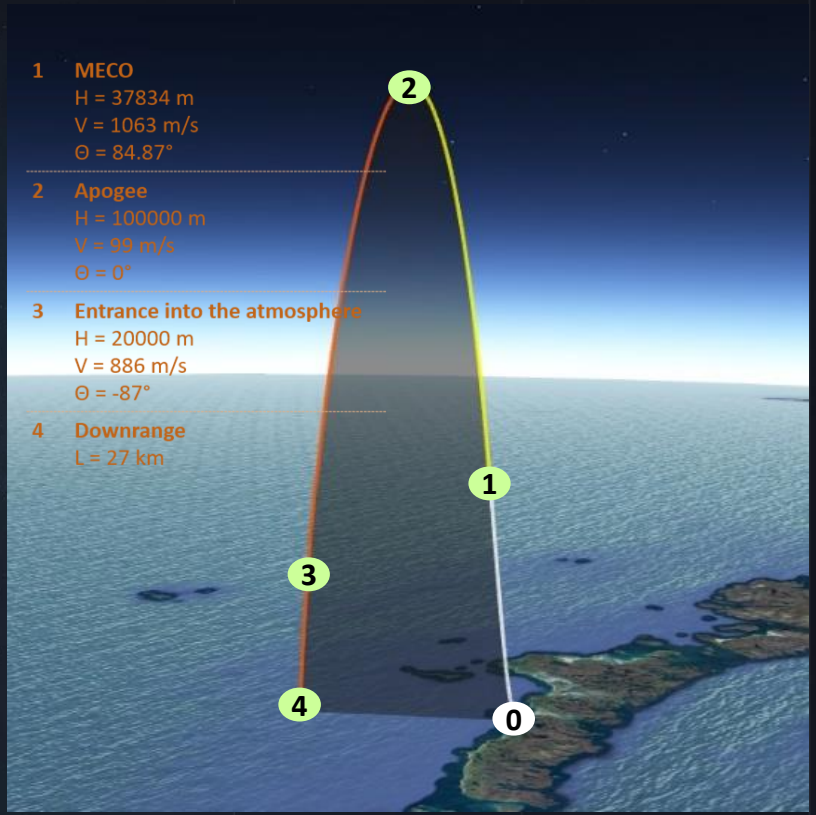
- Meteorological weather balloons provide accurate weather information for trajectory analysis and enable go/no go for launch decision making

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



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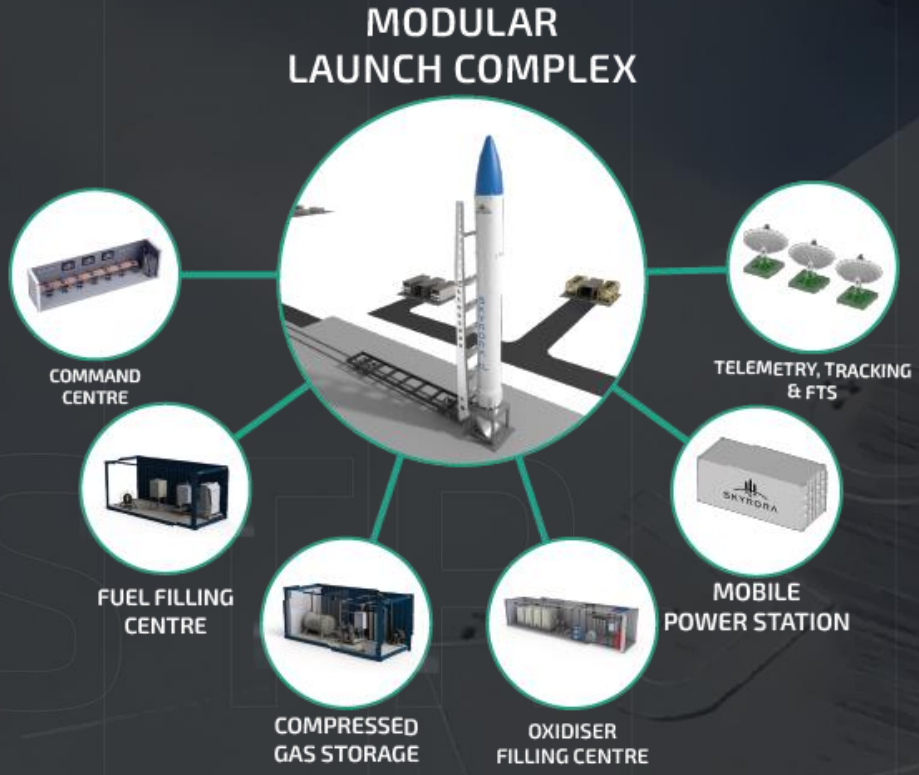
Modular Launch Complex



SKYRORA XL

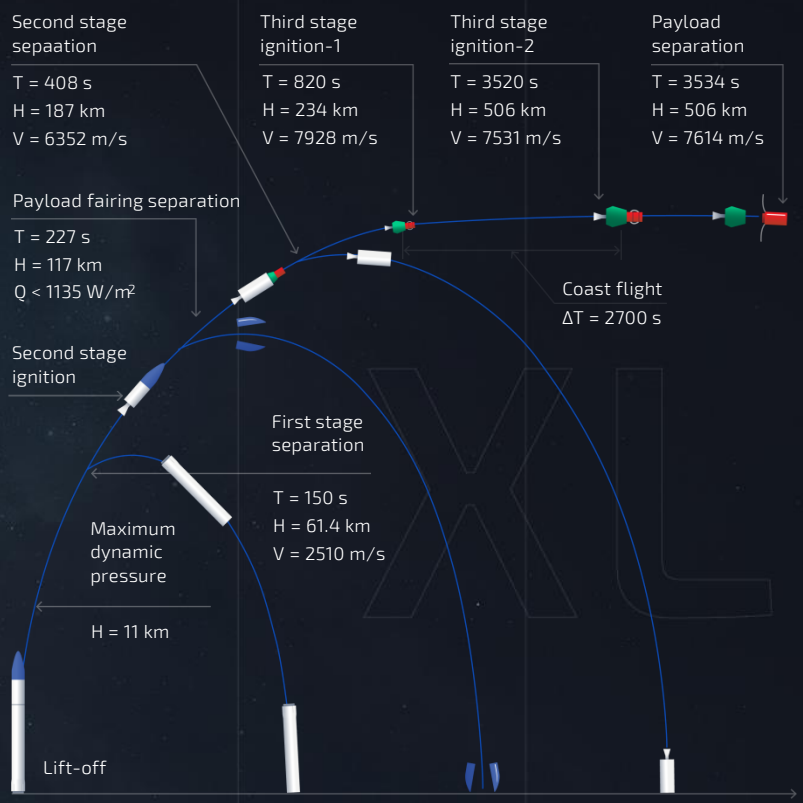
Skyrora XL is a three-stage orbital launch vehicle designed to launch a 315 kg payload to Polar and Sun-synchronous orbits

Engines are powered by advanced turbopump techniques and liquid propellants

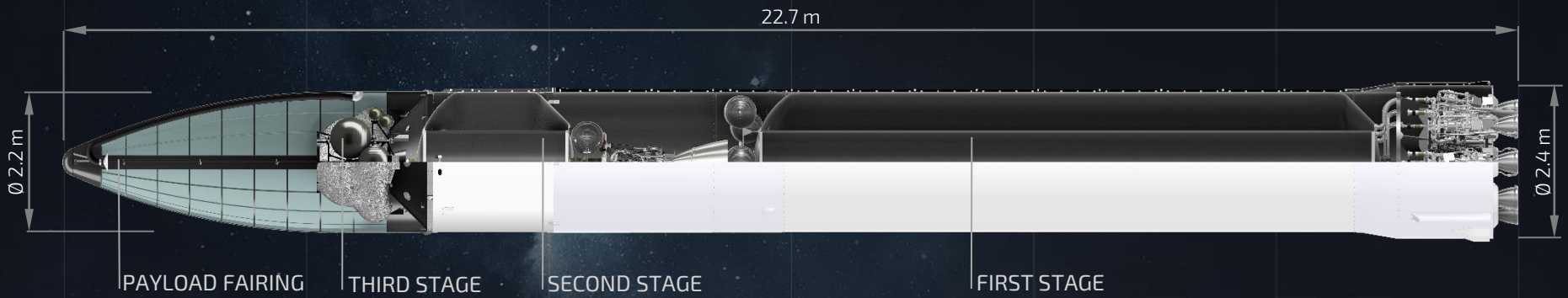
REIGNITABLE THIRD STAGE

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

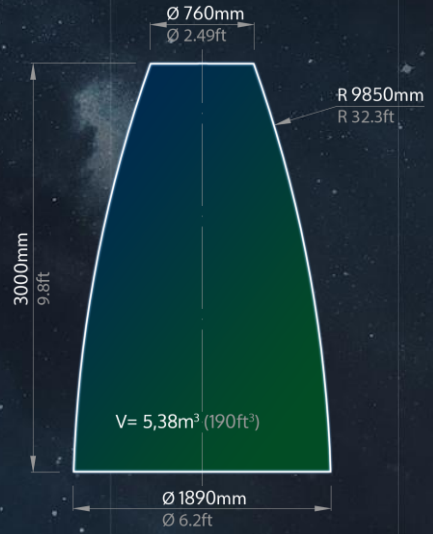
Re-ignitable 3rd stage engine enables precise bespoke and highly effective orbits. This service currently unavailable from vast majority of competitors

COST EFFICIENCY

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

SKYRORA XL PAYLOAD ACCOMODATION

PAYLOAD VOLUME



TECHNOLOGY READINESS LEVEL

TRL-2

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

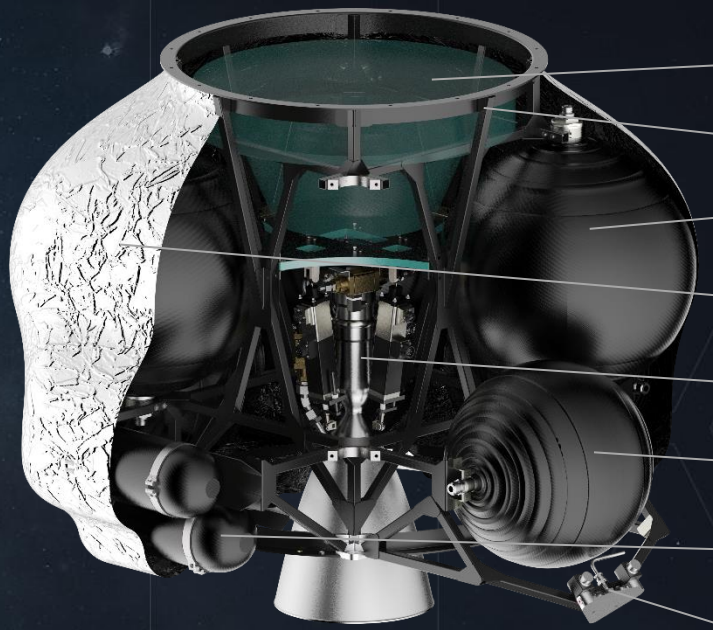
Dry mass	314 kg
Loading mass	590 kg
Propellant:	
- oxidizer	Hydrogen peroxide
- fuel	Kerosene, Ecosene
Propellant feed system	Pressure-fed
Engine thrust in a vacuum	3500 N
Numbers of engine ignition	Up to 11
Attitude control	Electro actuator TVC

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

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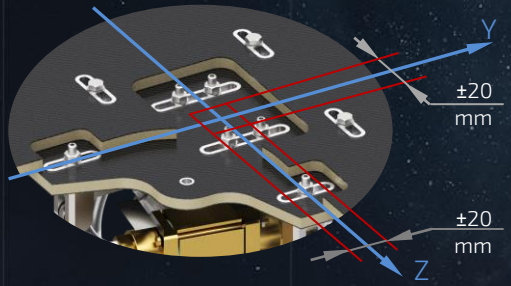
POSITION ADJUSTMENT



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.

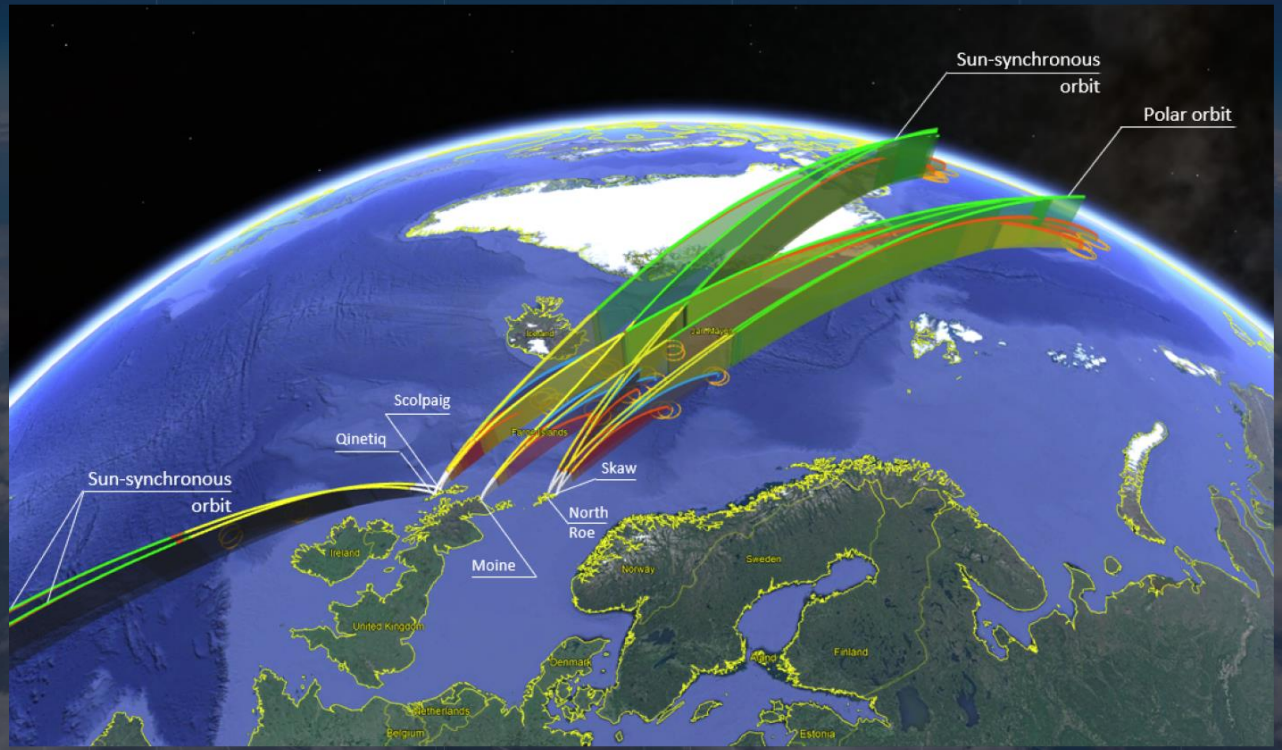
The space tug is designed to be compatible with both the upper stage of the launch vehicle and payload components to enable a partner launch vehicle.

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

SKYRORA

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

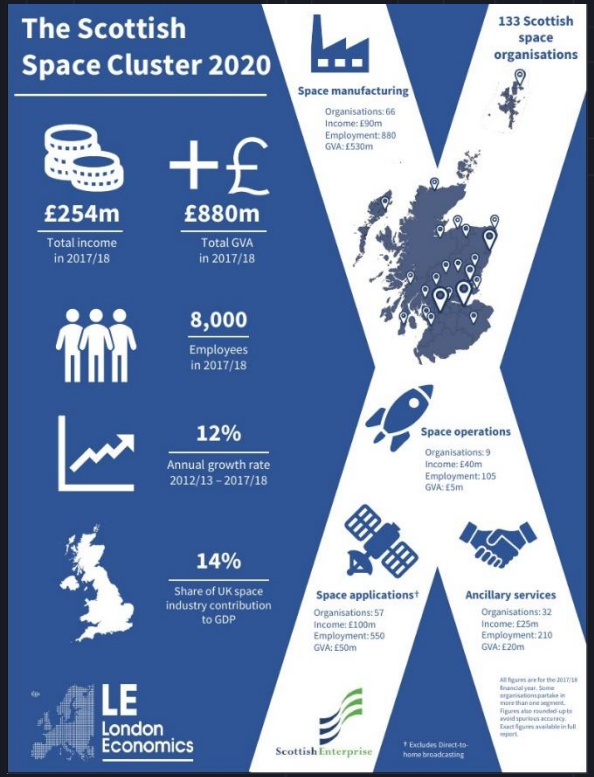
BY 2030 SKYRORA will:

- 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 – infrastrucuture – 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;



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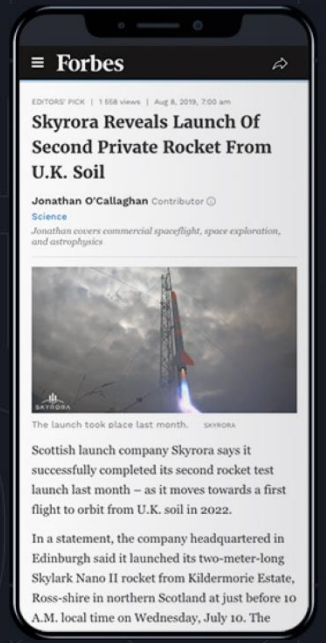

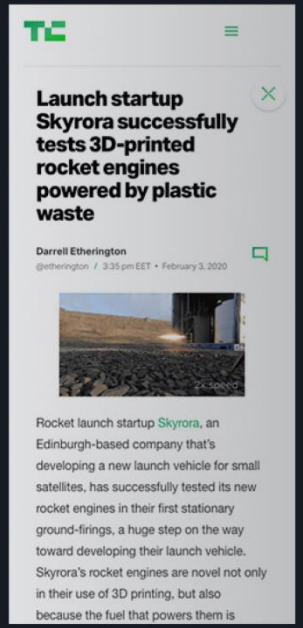

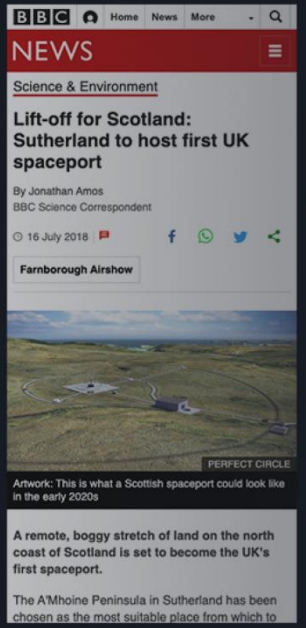

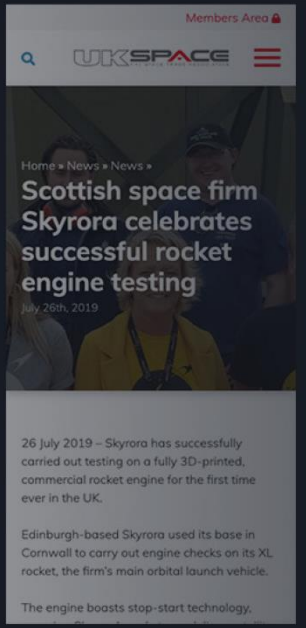

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