XCOR

Developing the Next Generation Spaceplane

Erik Seedhouse

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To: Jeff Greason and his team of dedicated engineers for bringing the Lynx to reality

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About the Author

Erik Seedhouse is a fully trained commercial suborbital astronaut. After completing his first degree, he joined the 2nd Battalion the Parachute Regiment. During his time in the "Para's," Erik spent six months in Belize, where he was trained in the art of jungle warfare. Later, he spent several months learning the intricacies of desert warfare in Cyprus. He made more than 30 jumps from a Hercules C130 aircraft, performed more than 200 helicopter abseils, and fired more light anti-tank weapons than he cares to remember!

Upon returning to academia, the author embarked upon a master's degree which he supported by winning prize money in 100 km running races. After placing third in the World 100 km Championships in 1992, Erik turned to ultra-distance triathlon, winning the World Endurance Triathlon Championships in 1995 and 1996. For good measure, he won the World Double Ironman Championships in 1995 and the infamous Decatriathlon – an event requiring competitors to swim 38 kilometers, cycle 1,800 kilometers, and run 422 kilometers. Non-stop!

In 1996, Erik pursued his Ph.D. at the German Space Agency's Institute for Space Medicine. While studying, he found time to win Ultraman Hawai'i and the European Ultraman Championships as well as completing Race Across America. Due to his success as the world's leading ultra-distance triathlete, Erik was featured in dozens of magazine and television interviews. In 1997, *GQ* magazine nominated him as the "Fittest Man in the World."

In 1999, Erik took a research job at Simon Fraser University. In 2005, he worked as an astronaut training consultant for Bigelow Aerospace and wrote *Tourists in Space*, a training manual for spaceflight participants. Between 2008 and 2013, he served as director of Canada's manned centrifuge and hypobaric operations and, in 2009, he was one of the final 30 candidates in the Canadian Space Agency's Astronaut Recruitment Campaign. Erik has a dream job as a professor in Commercial Space Operations at Embry-Riddle Aeronautical University in Daytona Beach, Florida. In his spare time, he works as an astronaut instructor for Project PoSSUM, a professional speaker, a triathlon coach, and an author. *XCOR* is his 24th book. When not enjoying the sun and rocket launches on Florida's Space Coast, he divides his time between his second home in Sandefjord, Norway, and Waikoloa on the Big Island of Hawai'i.

Acronyms

AASA	Axe Apollo Space Academy
AEM	Animal Enclosure Module
AFT	Autogenic Feedback Training
AGSM	Anti-G Straining Maneuver
AIM	Aeronomy of Ice in the Mesosphere
ARC	Ames Research Center
ATV	Atmospheric Test Vehicle
BPPV	Benign Paradoxical Positional Vertigo
CAA	Civil Aviation Administration
CCL	Commerce Control List
CEF	Change Evaluation Form
COMSTAC	Commercial Space Transportation Advisory Committee
CP	Cowling Port
CRM	Crew Resource Management
CRuSR	Commercial Reusable Suborbital Research
CS	Cowling Starboard
CSF	Commercial Spaceflight Federation
CSLA	Commercial Space Launch Amendments
DARPA	Defense Advanced Research Projects Agency
ECG	Electrocardiogram
ECLSS	Environmentally Controlled Life-Support System
EPT	Effective Performance Time
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
FAI	Fédération Aéronautique Internationale
FAR	Federal Aviation Regulations
FFD	Final Frontier Design
FOP	Flight Opportunities Program
FRR	Flight Readiness Review

G-LOC	Gravity-Induced Loss of Consciousness
GOR	Gradual Onset Rate
HAI	High-Altitude Indoctrination
HEPA	High-Efficiency Particulate Air
HFA	Hardware Feasibility Assessment
HMD	Head-Mounted Display
HSG	High Sustained G
HTPB	Hydroxyl-Terminated Polybutadiene
ICB	Informal Consent Briefing
ICD	Interface Control Document
ICP	Intracranial Pressure
IPP	Innovative Partnership Program
ISS	Integrated Spaceflight Service
ITAR	International Trade on Arms Regulations
LEO	Low Earth Orbit
LoV	Loss of Vision
LPMR	Layered Phenomena in the Mesopause Region
MASS	Mesospheric Aerosol Sampling Spectrometer
MCAT	Mesospheric Clear Air Turbulence
MCC	Mission Control Center
MCP	Mechanical Counter Pressure
MRI	Magnetic Resonance Imaging
NAUI	National Association of Underwater Instructors
NITE	Noctilucent cloud Imagery and Tomography Experiment
NSRC	Next Generation Suborbital Researchers Conference
PAR	Payload Anomaly Report
PGSC	Payload and General Support Computer
PI	Principal Investigator
PIM	Payload Integration Manager
PLL	Peripheral Light Loss
PMC	Polar Mesospheric Clouds
PMR	Post-Mission Report
PoSSUM	Polar Suborbital Science in the Upper Mesosphere
PSD	Physiological Support Division
PSI	Planetary Space Institute
PUG	Payload Users Guide
RCS	Reaction Control System
RD	Rapid Decompression
REM	Research Education Mission
RLV	Reusable Launch Vehicle
ROR	Rapid Onset Rate
ROSES	Research Opportunities in Space and Earth Sciences
RRL	Rocket Racing League
SARG	Suborbital Applications Researchers Group
SD	Slow Decompression

SMS	Space Motion Sickness
sRLV	Suborbital Reusable Launch Vehicle
SSI	Space Science Institute
SSME	Space Shuttle Main Engine
SSTO	Single Stage to Orbit
SSTP	Suborbital Scientist Training Program
STEM	Science Technology Engineering and Mathematics
STMD	Space Technology Mission Directorate
SwRI	Southwest Research Institute
USAF	United States Air Force
USML	United States Munitions List
USRA	Universities Space Research Association
VFR	Visual Flight Regulations
WFI	Wide Field Imager

Preface

For years after SpaceShipOne won the X-Prize, all you ever heard in the commercial spaceflight business was when SpaceShipTwo would begin revenue flights. Initially, Paris Hilton and her celebrity friends were due to take their suborbital joyride in 2007, but an explosion that killed three workers put paid to that deadline. Then 2010 was announced as the start of revenue operations but, by the end of 2010, still no passengers had flown. 2010 became 2011, which became 2012 and still there were no flights. Then, tragically, in October 2014, SpaceShipTwo crashed, killing one of the pilots and injuring the other. The public wondered whether passengers would ever fly in space, oblivious to the work of a company that also had suborbital aspirations and which was located just a stone's throw down the flight line from Virgin Galactic. That company's name is XCOR and its snappy little spaceship is the Lynx.

The Lynx has been in the works for years, but XCOR, unlike some companies, prefer to let their deeds to the talking. No bold pronouncements of when revenue flights will start from this company. Over the years, XCOR has amassed invaluable expertise in the building of suborbital vehicles: in addition to having developed and built 13 different rocket engines, XCOR has also accumulated more than 4,000 engine firings and more than eight hours of run time on their engines. With the travails of Virgin Galactic putting the future of SpaceShipTwo on a back foot, XCOR has been thrust into the spotlight of the commercial space industry and is on the cusp of conducting flight testing of the Lynx Mark I.

The Lynx has two seats – one for a pilot and one for a spaceflight participant. Its low weight and high-octane fuel confer important advantages over SpaceShipTwo that include direct runway launches without the complication and expense of a mother ship and the ability to fly several times per day. Like SpaceShipTwo, the Lynx is a rocket-powered airplane, but that's about the only similarity. Powered by four XCOR-built kerosene and liquid-oxygen engines, the Lynx's take-off speed is 190 knots, and it can get airborne with only 350 meters of runway. The all-liquid design is more efficient than SpaceShipTwo's hybrid propulsion, providing more thrust per pound of fuel. All-liquid fuel should also give the Lynx a fast turnaround between flights because crews can just top up the tanks and fly again, whereas SpaceShipTwo's engine must be replaced between flights.

Passengers paying US$150,000 ($100,00 less than Virgin Galactic's ticket price) will ride beside the pilot. Both pilot and passenger will wear pressure suits as a safety measure in case cabin pressure is lost during the flight. Unlike SpaceShipTwo customers, Lynx passengers will not be able to unstrap and float about the cabin after the engine cut-off. All being well, revenue flights could start sometime in 2019. That's 15 years after the X-Prize-winning flight of SpaceShipOne and there may be some who are wondering why this suborbital spaceflight business has taken so long. The answer is money. XCOR never had the deep pockets of a Virgin Galactic, a SpaceX, or a Blue Origin. This is a company that has accomplished what many industry wags thought impossible on a budget that NASA uses to put together a few PowerPoint presentations. And it has done so thanks to the incredible dedication and perseverance of a handful of extraordinarily talented individuals who had the intestinal fortitude to take risks and to dream big. Take Jeff Greason for example. We'll talk about Jeff at some length in this book but here's a snapshot of the man with the vision that morphed into what XCOR is today.

The XCOR team. Credit: XCOR

Jeff has been space enthusiast his whole life so, when an opportunity to take the job as head of propulsion with Rotary Rockets came about in 1997, he jumped at the chance. It was a bold – some may say reckless – move, given that he left a lucrative career as an

engineer with Intel, but "bold" is what Jeff does. Two years later, Rotary folded and Greason, together with a small group of Rotary engineers, formed XCOR. More than 16 years later, they are still together[1] and are on the cusp of making history as the first company to start a suborbital flight service. And, when that service starts, the pilot at the controls will likely be three-time Shuttle astronaut Rick Searfoss. With Searfoss and his passenger ensconced in their pressure suits, the Lynx will taxi off the ramp and wait for clearance from the tower at Midland. Once clearance has been given, the Lynx will get airborne in seconds thanks to the eye-popping acceleration provided by those engines. Less than a minute after take-off, the Lynx will be accelerating through Mach 1 and the sky that was blue just a few seconds earlier will rapidly fade to black. With the flip of a few switches, Searfoss will shut down the engines and momentum will do the rest as the vehicle coasts to its apex more than 100 kilometers above Earth. There, for up to four minutes, passengers – now astronauts – will take in the jaw-dropping view, unless they happen to be scientists, in which case they will have to knuckle down to following their checklists. All too soon, the suborbital joyride will be over and the Lynx will glide back to its home airport, ready to do it all over again.

[1] In November 2015 it was announced that Jeff, together with two other founders of XCOR Aerospace, were leaving the company to form Agile Aero. While Jeff remains on the board, he is no longer involved in XCOR's day-to-day operations.

1

XCOR: A Brief History

Credit: XCOR

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In 1999, XCOR comprised four employees who had just been laid off from Rotary Rocket. With no money, no investors, and little in the way of a business plan, they decided to strike out on their own and founded XCOR (*www.xcor.com*). Fifteen years and US$45 million (mostly raised from venture funds) later, XCOR is on the threshold of commercial suborbital passenger operations – all for US$150,000 a ticket.

XCOR has never been a large company, but what it lacks in size it more than makes up for in innovation. While other companies in the New Space era have crashed and burned – think Kistler and Starchaser – XCOR has grown from strength to strength. The reason is simple: XCOR is one of the few companies in the commercial spaceflight arena that can successfully translate their plans to products – a skill they have repeated over and over again since the company's inception in 1999. Back then, the Mojave-based company's project was the NeX-1. The Nex-1, a replica of Chuck Yeager's Bell X-1 (Figure 1.1), was a much more down-to-earth affair compared with the Lynx, since it was merely intended to be shown at air shows. As part of the NeX-1 project, XCOR redesigned the XLR-11 engine that provided the power for the X-1.

Why the NeX-1? At the time, XCOR's plan was to provide high-altitude, Mach-speed joyrides – a precursor to space tourism. It was a bold move back in 1999 because space tourism was a decidedly risky business proposition given that it would be five years before

1.1 The X-1 rocket plane. Credit: NASA