This is NOT a presentation about the SpaceShipOne (Tier-1) test program nor about details of the design and fabrication of SS1 and its systems.

This presentation tells the story of how a small aircraft development company approached the challenge of sub-orbital manned spaceflight, and the lessons learned from the experience.
Paul Allen

An unusual aerospace customer.

The research opportunity was unique, due to Paul’s passion for spaceflight.

Paul was a customer that allowed those closest to the technical arena to make the decisions on what risks to take (critical for any research program).

This was a private contract for a program conducted covertly until the completed spaceship was unveiled.

Further information can be seen in Paul’s book “Idea Man”, and in two Discovery video documentaries titled “Black Sky”.

Microsoft founders
Bill Gates & Paul Allen
Performance of Rutan-Designed Manned Aircraft
Pre-2004

Max Altitude (feet)

- O = Scaled Composites
- + = Rutan Aircraft

Maximum Speed (Knots)
The Big Jump into Space  2004

SpaceShipOne

Previous Performance Envelope
SpaceShipOne Baseline Mission

White Knight first stage
60-minute climb
Launch at 50-kft altitude

Rocket boost
48-kft to 170-kft
2.3-g Nz pull-up
80-sec acceleration
0.5 to 3.3 mach
Max q = 260 KEAS
Max Nx = 3.3-g vertical

Entry Deceleration
200-kft to 85-kft
60-sec deceleration
Max-g = 5.5 at 105-kft
Max q is 160 KEAS
Above 4-g for 16 seconds
Mach 3.2 to 0.5

Glide after De-Feather
80-kft to landing
22 minutes at 105 KEAS
Max range available > 60 miles
Touchdown at 75 KEAS

3.5 minute weightless
Apogee > 100-km (328-kft)
Feather while weightless

White Knight first stage
60-minute climb
Launch at 50-kft altitude

Max q = 260 KEAS
Max Nx = 3.3-g vertical
The View from 120 Km altitude

- 70-mile apogee
- Canada
- Launch aircraft 50,000 foot
History

Manned Sub-orbital Space Flight

Altitude greater than 100 km
Four flights, all more than 40 years ago

Mercury-Redstone
Alan Shepard - 1962
Gus Grissom - 1962

B-52 and X-15
Joe Walker
Two flights in 1963
Comparison with X-15 - 100-km altitude mission

• Program Goal, primarily high speed
• Trajectory ~ 40 deg for boost and entry
• Weightless for ~ 3.5 minutes
• Pilot-controlled pull-up during entry
• Entry max q ~ 1000 psf (550 KEAS)
• Lakebed landing
  - 270 - KEAS approach
  - 180 - KEAS touchdown

• Program Goal, altitude & view
• Trajectory ~ near-vertical
• Weightless for ~ 3.5 minutes
• “Care-free” entry ~ 60 deg AOA
• Entry max q ~ 80 psf (160 KEAS)
• Runway landing
  - 105 - KEAS approach
  - 75 - KEAS touchdown
Brief Outline of Program milestones:

First rocket ground firing (With flight components, 15-sec burn) – 21 Nov 02.
Fabrication start, SS1 – May 2002. Rollout SS1 April 03.
Launch aircraft demo flight during SS1 unveiling - 18 April 03 (WK1 flight 21).
Un-manned captive carry of SS1 - 20 May 03 (WK1 flight 24).
Full-duration ground firings eAc – 24 Jul 03, SpaceDev – 31 Jul 03.
Manned captive carry of SS1 – 29 July 03.
First Glide of SS1 - 7 Aug 03. Second glide flight, including feathered descent, 27 Aug 03.
First Rocket flight of SS1 (supersonic climb, 15-second burn) – 17 Dec 03 (100 yr. after WB).
First 100+ km space flight (The major Program Goal) – 21 June 2004.
An Aggressive Flight Test Program

- **White Knight, Pre-Spaceship**
  - Performance, Stability & Space Systems Development
  - 56 flights, 10 Months

- **Rocket Hot-Fire Ground Tests**
  - R & D - nine months, eleven firings
  - Flight qualification - Three Firings

- **SpaceShipOne Flight Tests**
  - Two captive carry (one manned)
  - Glide tests - 7 glides, 4 months
  - Rocket Powered Envelope Expansion – 4 flights, last one >100km
  - X-Prize – 2 full-performance flights in 5 days
Some Early concept sketches for SS1

Model 267, Feb 1995
Yep, a real napkin sketch

Model 280, Apr 1996
Propulsion separates after boost.
Original Launch Concept
1995
A Proteus design constraint

Proteus, offset mounting

Launch after pull-up
Altitude ~ 27,000 ft
Gamma = 40+ degrees
Selected Configuration
Mid 2000

- Level launch, boost-pull to vertical
- “Care-free” entry, “feathered” wing-tail
- Glide landing on runway
Model 318 White Knight and Model 316 SpaceShipOne
Configuration when Paul Allen Contract started (March 2001)
Some selected slides
Early Program Description
Air Launch

A new dedicated Launch Aircraft (Model 318) releases the Spaceship in level flight above 50,000 feet.

Launch Aircraft also functions as a Spaceship training platform and Spaceship systems development tool.
Boost phase is at low q - start high and go steep

- After air launch, the spaceship glides clear, then ignites the rocket motor.
- Pull-up and accel to Mach 3+ vertical velocity.
- Low aero loads during boost due to high launch altitude.
- Burnout occurs within the atmosphere. Spaceship then coasts out of the atmosphere.
- Simple control system: elevons and rudders control trajectory during boost. Electric stab trim augments the manual control at high-q.
- Propulsion thrust vector control system is not required.
Atmospheric entry is carefree using single-mode, super stability

- Single-mode, super-stability (feather shuttlecock) for entry.
- Trim controls azimuth, other axes are passive/carefree.
- All reversible controls are ineffective during entry.
- Low ballistic coefficient, low thermal protection required.
- Max reentry g occurs above 100,000 ft. Subsonic below 85,000 ft.
- Low aero loads. Dynamic pressure only 15% of the X-15. Max g is less than 6. Approximately 20 sec time above 3 g.
- Feather retraction occurs during subsonic descent (pilot option 10,000 ft to 80,000 ft).
Pilot Training and Qualification

- **Fixed-base Simulator**
  - Actual spaceship cockpit with all flight controls
  - Flight hardware avionics for flight director
  - Full-flight performance simulation
  - Projection TV outside view
  - Helmet forces for g-simulation, 2 axis

- **Launch aircraft has SpaceShip cockpit**
  - Identical: seats, windows, controls & avionics
  - Flight director commands pull-up for boost training
  - Zoom at low altitude allows 20 sec of zero-g
  - Descending windup turn duplicates reentry g profile
  - Spoilers and drag brakes use SpaceShip controls and systems
  - Glide landing profile allows realistic approach training
Integrated Hybrid Propulsion System
New Design - Breakthrough In Simplicity

- Integrated liquid Nitrous/solid fuel hybrid
  - Simple mounting is light, robust and accurate
  - Nitrous tank mounts as a full SpaceShip structural bulkhead
  - Motor/fuel/nozzle component has single flange
  - Single valve: starting/throttle/shutoff/dump/vent
  - Significant reduction of leak paths/failure modes
  - Safe storage, non-toxic, self pressurizing, room temperature oxidizer
  - Safe storage, non-toxic, cast-in-place fuel
Seating and Crew Restraint

- Seats are a continuous composite shell
  - Light structure designed for energy absorption
  - Minimum hard-point attachments to Pressure vessel, removable
- Conformal crew-unique cushions are laced to seat structure
Avionics

• Navigation/Flight Director
  – New unit, based on FunTech RacerView INS/GPS system, battery operated
  – Flight director provides boost steering commands for trajectory and to projected reentry location
  – Flight director provides approach steering commands for projected touchdown location
  – INS calculates and displays position, attitude, alpha, beta and Ve
  – Backup system includes attitude/GPS/Vi/Hi

• Data system: T/M and on-board recording, analog and digital

• System to be tested on six applications before first space flight
  – Flight simulator for boost, RCS, glide and landing tasks
  – All full-scale propulsion tests
  – Aerobatic light aircraft for boost training
  – Range validations at 50,000 ft/200 miles on Proteus
  – Identical system used on the Model 318 launch aircraft
  – Glide tests with Spaceship
Aerodynamic Analysis

- CFD: Fluent & other codes
- Stability and controllability analysis for all flight modes
  - Subsonic for launch, pull-up, glide and landing
  - Transonic and supersonic for boost
  - High angle of attack separated, supersonic flow for reentry (shown)
  - Control system failure modes
The Re-entry Feather
Immune to accidents caused by entry flight controls

Forces Ship to a Stable High Alpha Condition
Active controls not needed
• High Drag = Lower loads & Lower Heat
• Result: ‘Care-Free’ atmospheric entry
Summary

• Goal is validation of business plan for pilot training or tourism
  – Adequate flights to verify specific affordability targets.
• Program is structured for brisk schedule at acceptable risk
  – Parallel development of launch aircraft, Spaceship, Avionics, propulsion and training systems.
  – High-risk propulsion internal components were competed using two vendors.
• Program is stand-alone: independent of outside assets
• New Intellectual Property
  – Model 316 Spaceship design
  – Carefree reentry concept
  – New hybrid motor configuration
  – Affordable Space avionics
  – Launch aircraft design
Rocket Propulsion Development

• A new Hybrid motor was developed in-house:
  – All-composite oxidizer tank with titanium flanges. ATK provided the final Cf filament-wind overwrap.
  – All-composite motor case/throat/nozzle integrated component. AAE provided the tape-wrap component.

• Interior components competed with two small vendors:
  – Both vendors supplied components for separate ground firings.
  – The selected vendors supplied components for the manned rocket flights. eAc components were selected for fill/dump/vent. SpaceDev components were selected for injector/valve/bulkhead/controller.
Propulsion Testing with eAc components
Propulsion Testing with SpaceDev components

Breech Test
Some other ground tests

- Cabin static pressure.
- ECS, CO2 scrubbing
- Window Damage Tolerance at 2x operating pressure (proof test at 3.5x)
- Flutter GVT
- Static load proof, feather structure.
Crewchief Steve Losey & aerodynamist Jim Tighe

loading a motor

Steve and his Baby Spaceship
Roll-out - Unveil

April, 2003  Customer was not identified until 9 months later.

WK unveiled airborne

Cliff Robertson and some friends

Mac Faget and Buzz Aldrin
X-Prize Award Event in St Louis
November, 2004
Scaled got the Trophy, Paul got the check.
X-Prize $
Distribution of the 10M$
Paul Allen, MAV, Scaled Employees, Scaled Stockholders
Collier Trophy
March, 2005
Designer of the Year – Design News

Jim Tighe  March, 2005
Aviation Week Award
March 2005
Smithsonian NASM
National Air and Space Museum Trophy
For Current Achievement
March, 2005
SpaceShipOne Installation
Milestones of Flight Gallery, National Air and Space Museum
October, 2005
Lessons Learned

• A talented team can, and should occasionally tackle a challenge well beyond their past performance. This is the only path that will sustain our market share of the research business.

• Always try to build a true competition when subcontracting work that involves research. The contracts for the rocket components structured an environment that saved cost, saved time and forced/allowed the competitors to take the risks needed to meet program goals.

• There is nothing like an exciting, historic, risky, milestone-related program to motivate technically-capable people. The future benefits for the individuals and for the company are real and sustainable.

• Programs like Tier1 encourage/allow the company to take future steps for growth and for building an environment that breeds the breakthroughs that are needed to stay competitive.