SpaceShipOne
Program Summary

By Burt Rutan

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.

Microsoft founders
Bill Gates & Paul Allen

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

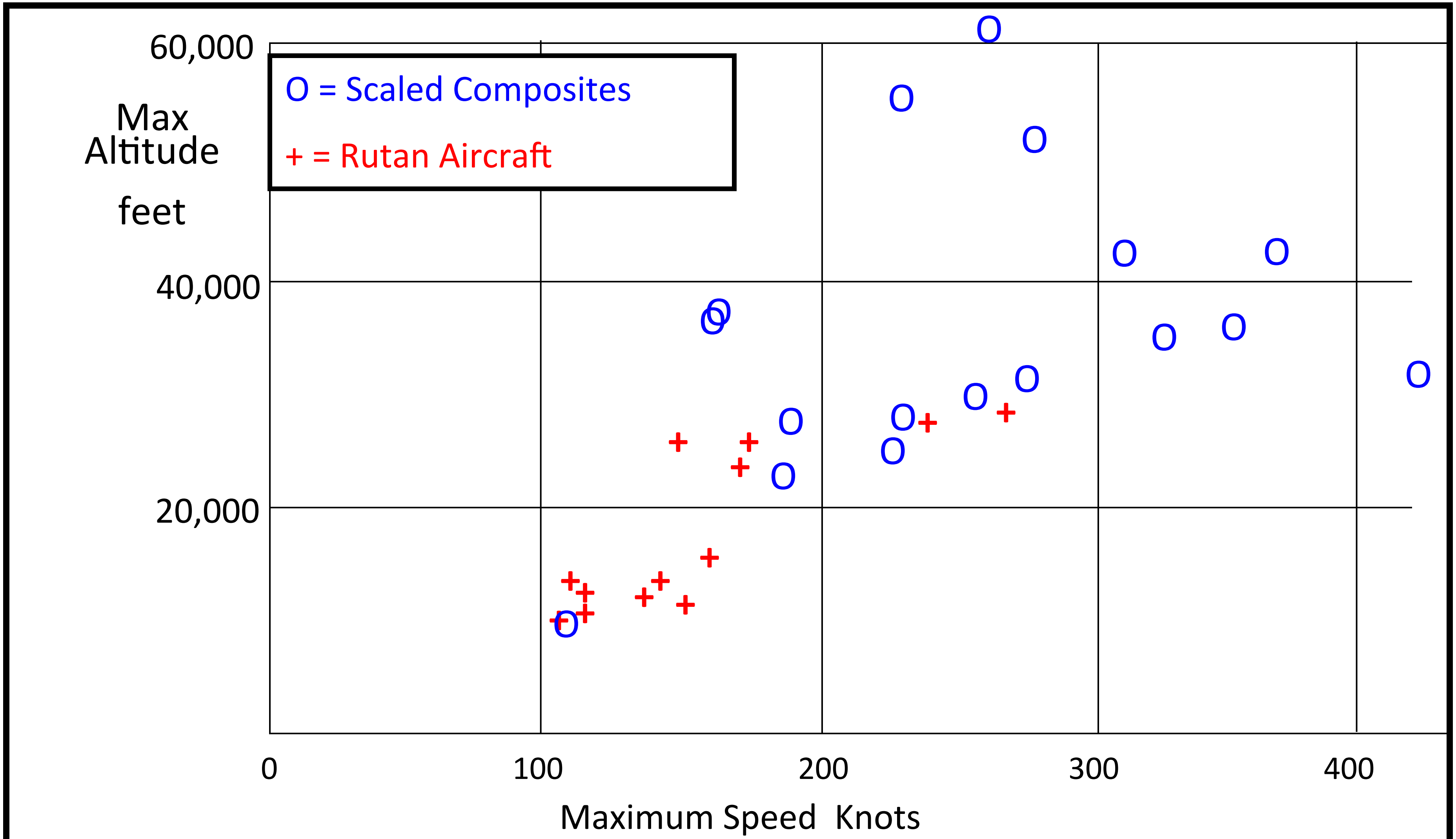
Paul was a customer that allowed those closest to the technical arena to make the decisions on what risks to take (critical for any research program).

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

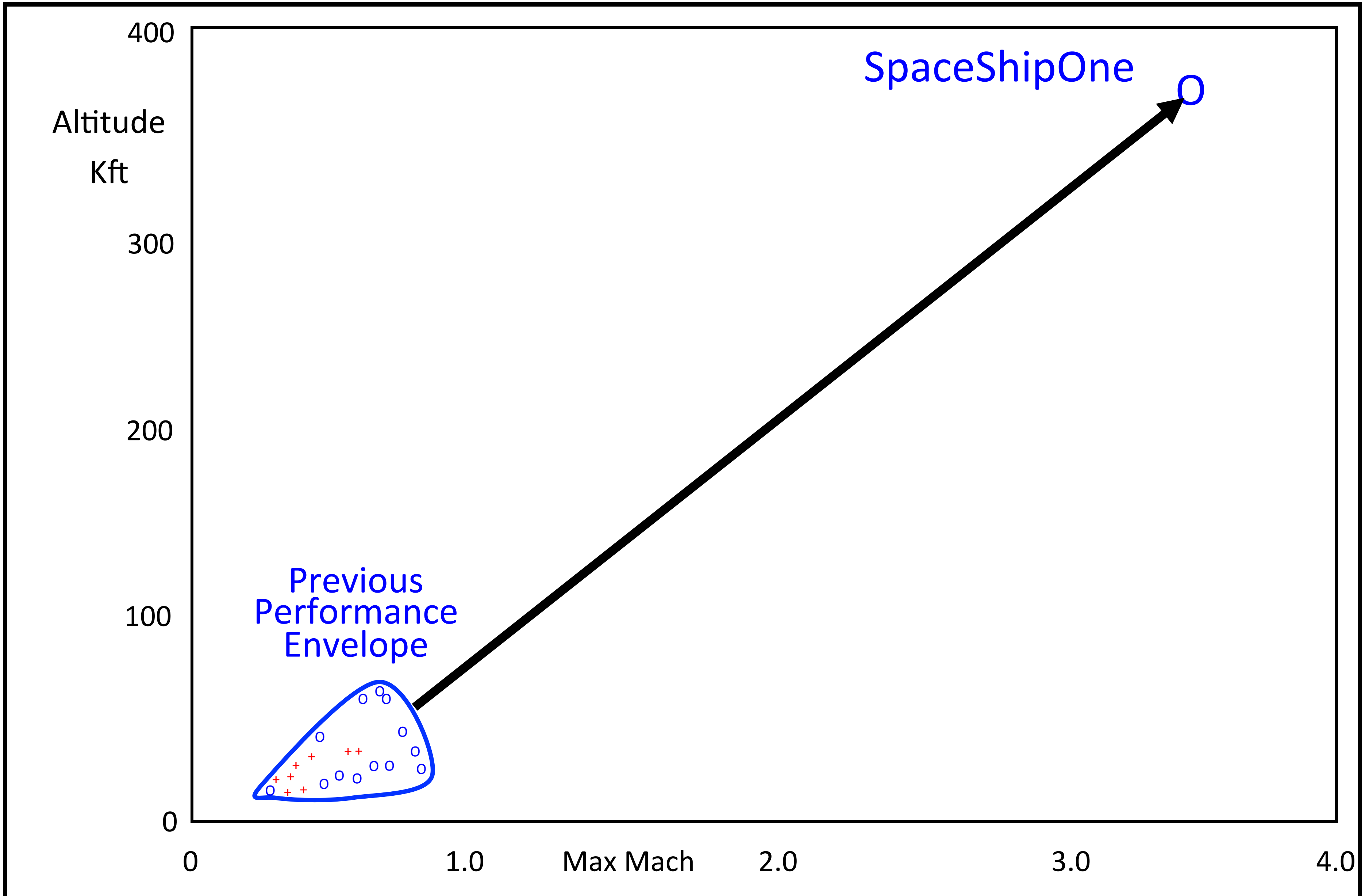
Further information can be seen in Paul's book "Idea Man", and in two Discovery video documentaries titled "Black Sky".

Performance of Rutan-Designed Manned Aircraft

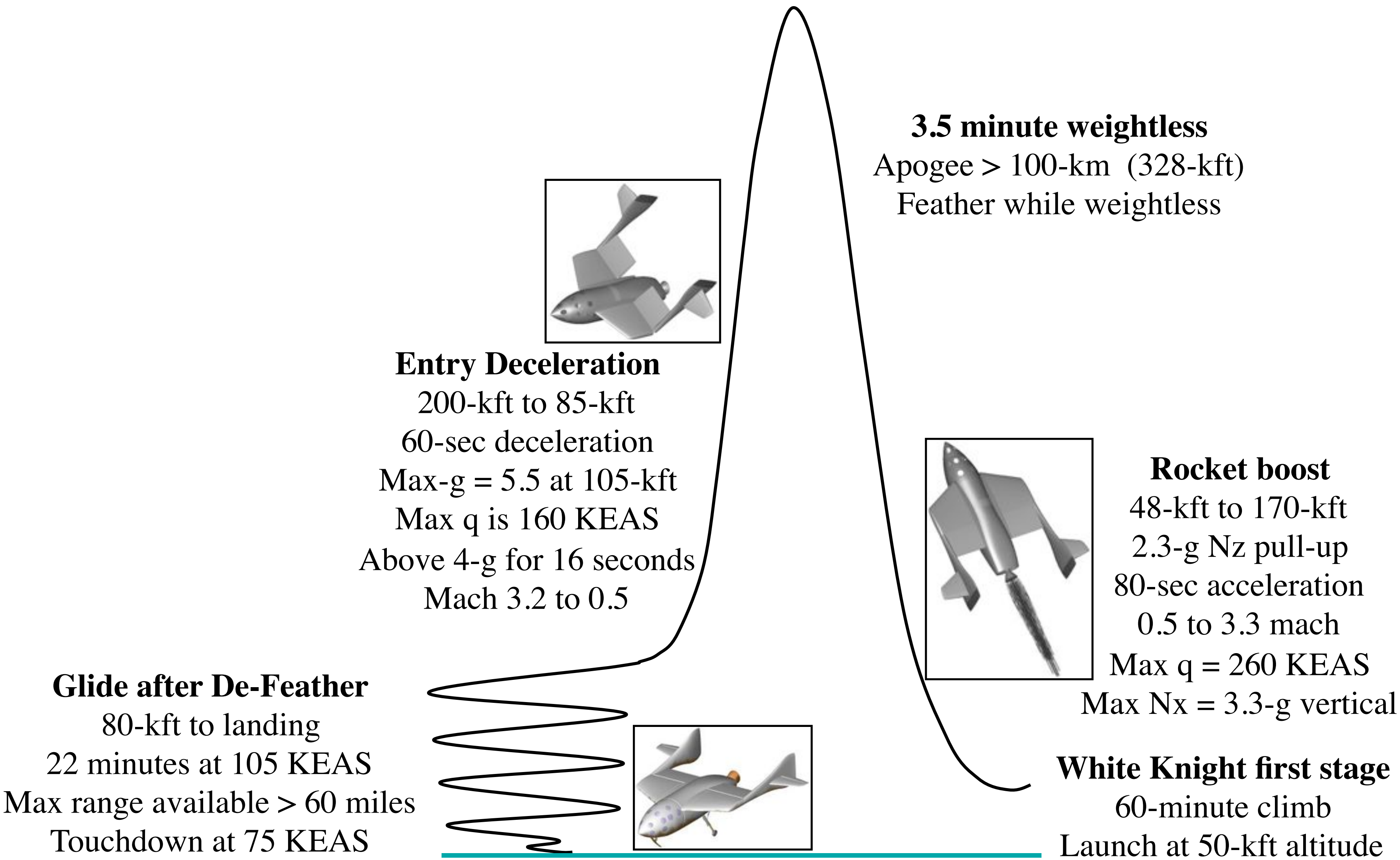
Pre-2004



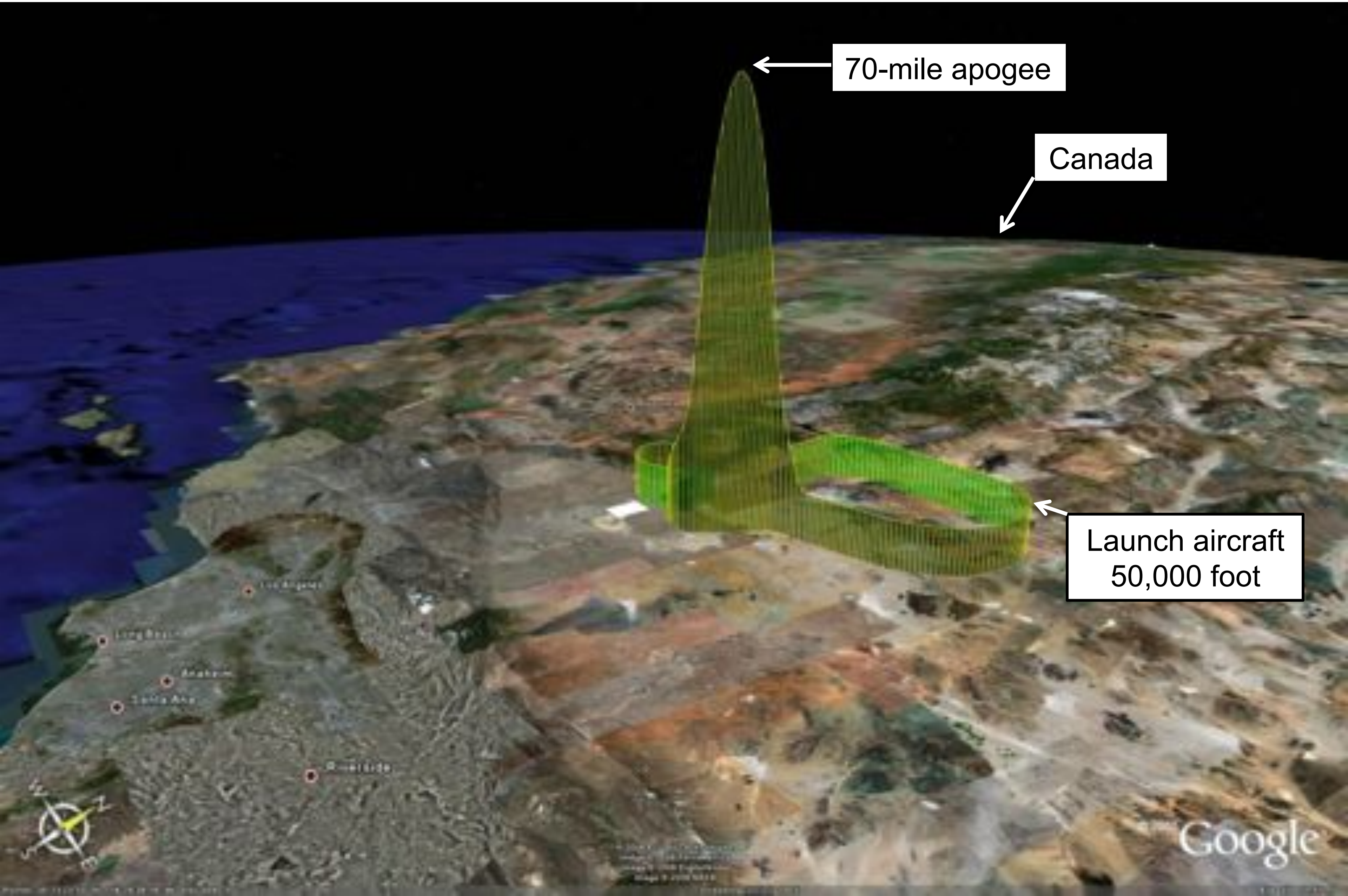
The Big Jump into Space 2004



SpaceShipOne Baseline Mission



The View from 120 Km altitude



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:

On contract with customer Paul Allen - March 2001.

Prelim design complete – WK1 May 2001, rocket motor July, 2001 and SS1 Jan, 2002.

Propulsion component contracts with eAc and SpaceDev – October, 2001.

Fabrication start, WK1 – June, 2001. First Flight WK1 – 1 Aug 02.

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.

X-Prize flights – 29 Sept 2004 and 4 Oct 2004.

Installation ceremony, Milestones of Flight Gallery Smithsonian NASM – October 2005.

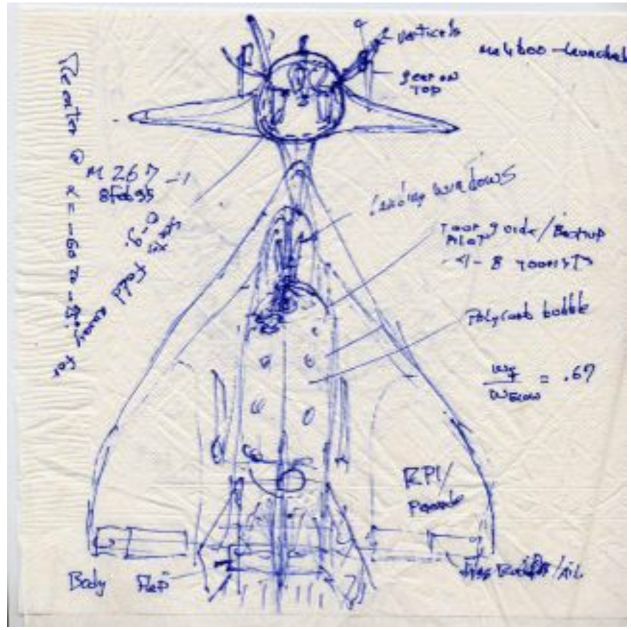
An Aggressive Flight Test Program

- 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

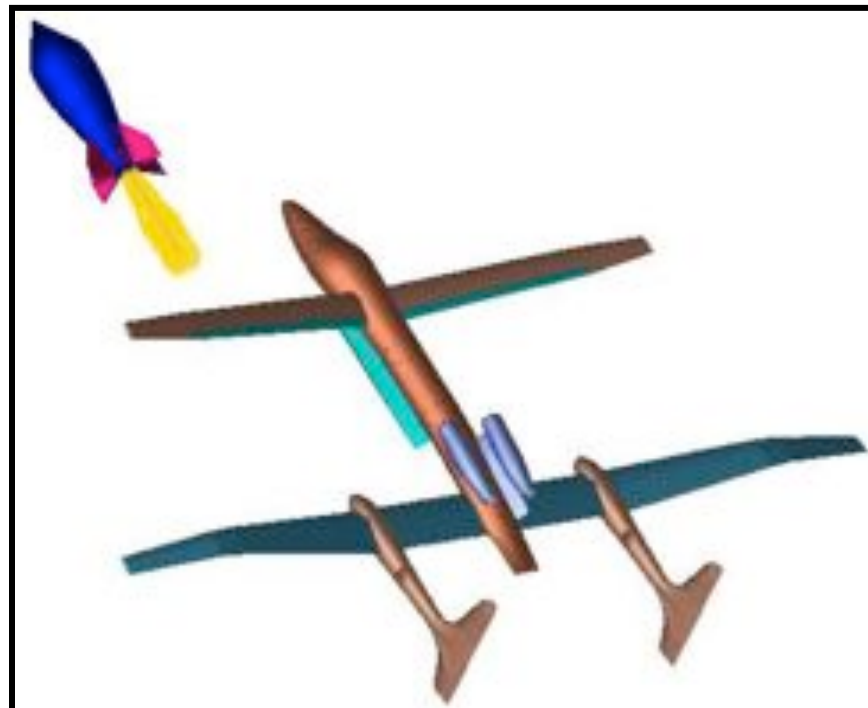
A Proteus design constraint

Proteus, offset mounting

Launch after pull-up

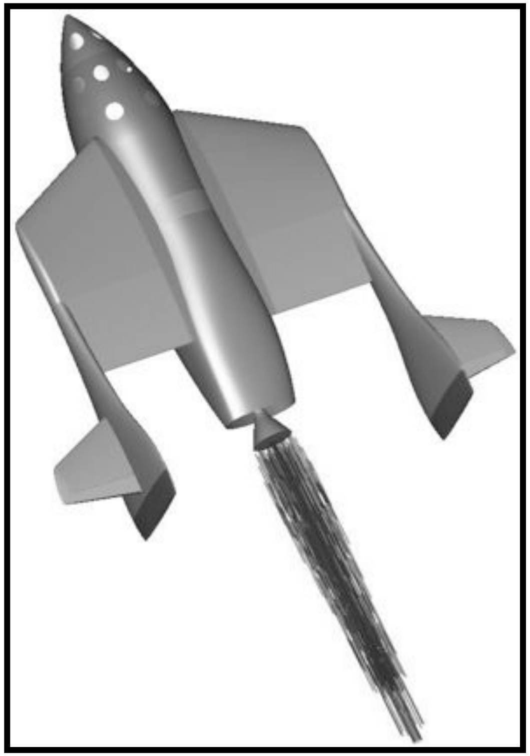
Altitude ~ 27,000 ft

Gamma = 40+ degrees

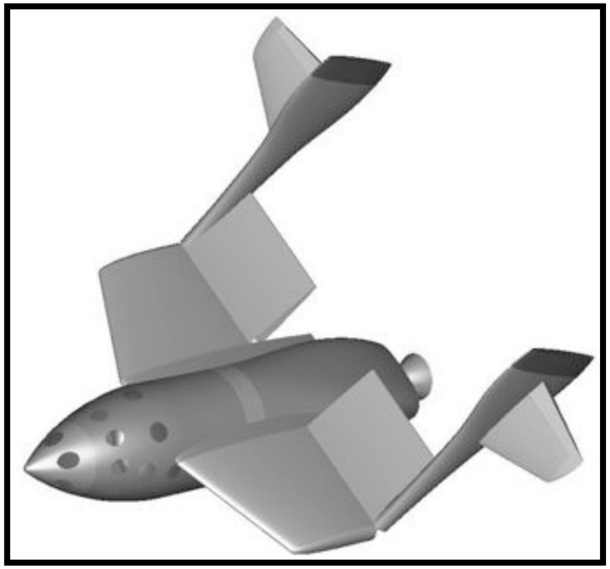


Selected Configuration

Mid 2000

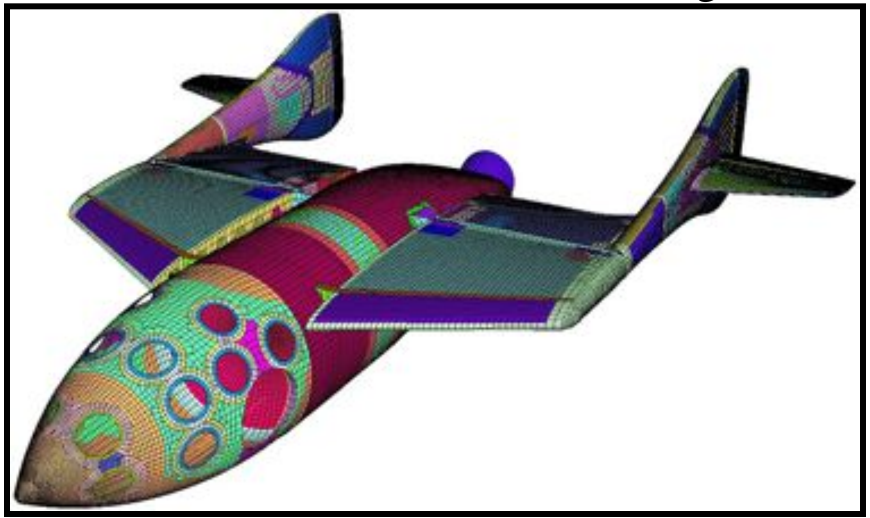


- Level launch, boost-pull to vertical
- “Care-free” entry, “feathered” wing-tail
- Glide landing on runway



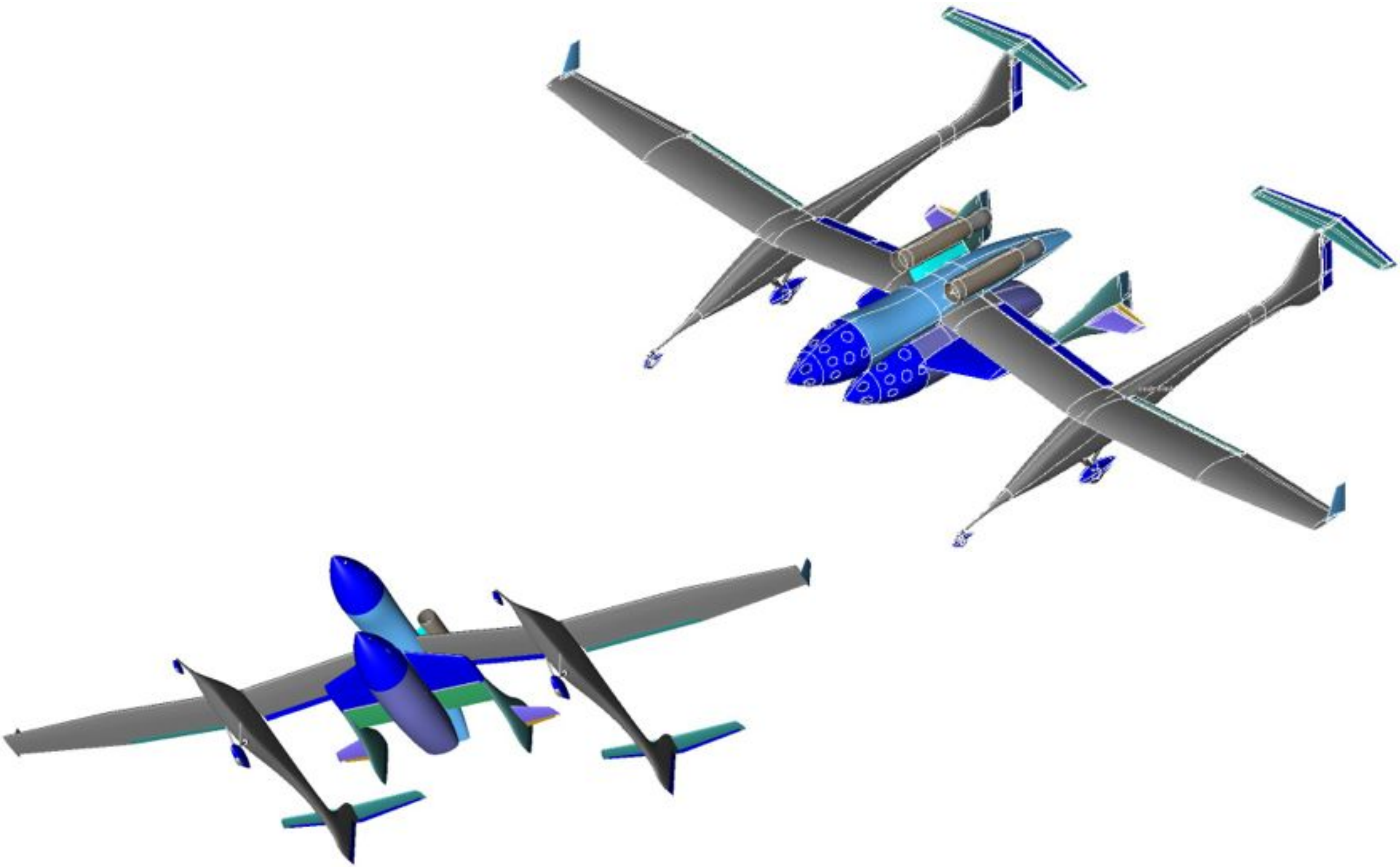
Boost & Landing Configuration

Entry Configuration



M0del 318 White Knight and Model 316 SpaceShipOne

Configuration when Paul Allen Contract started (March 2001)

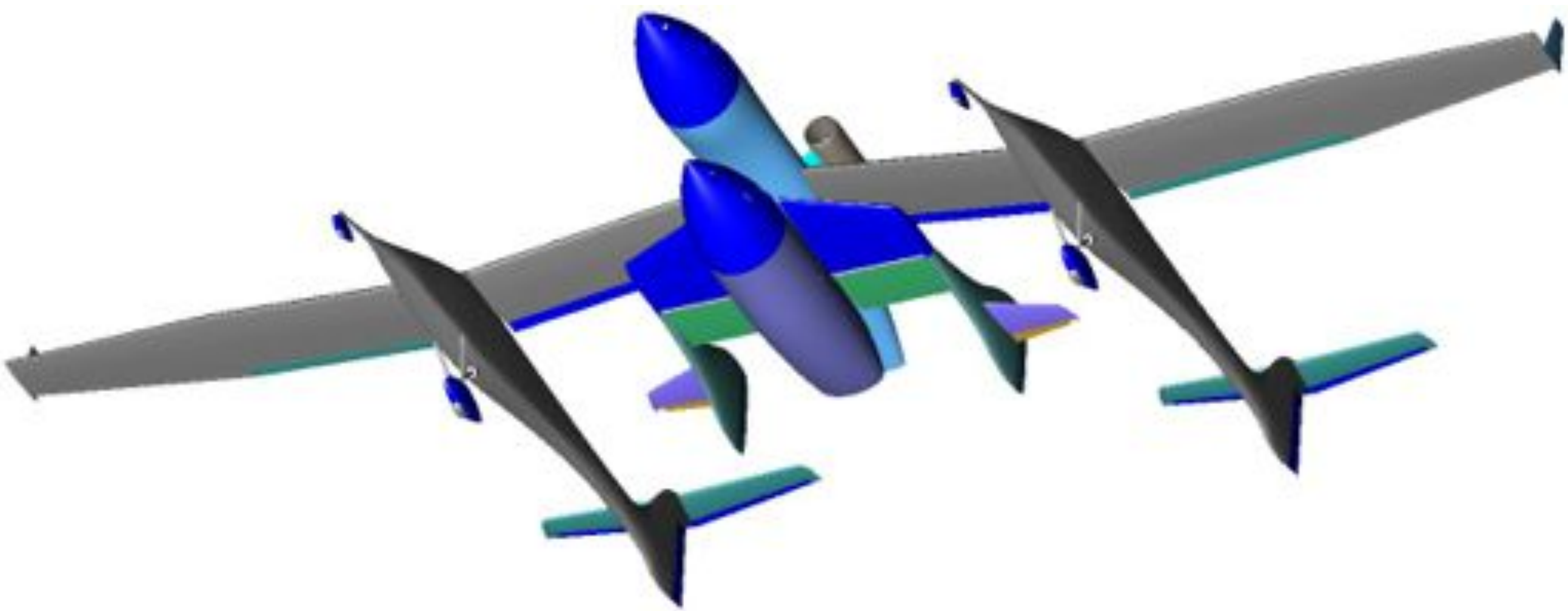


Some selected slides
Early Program Description

Air Launch

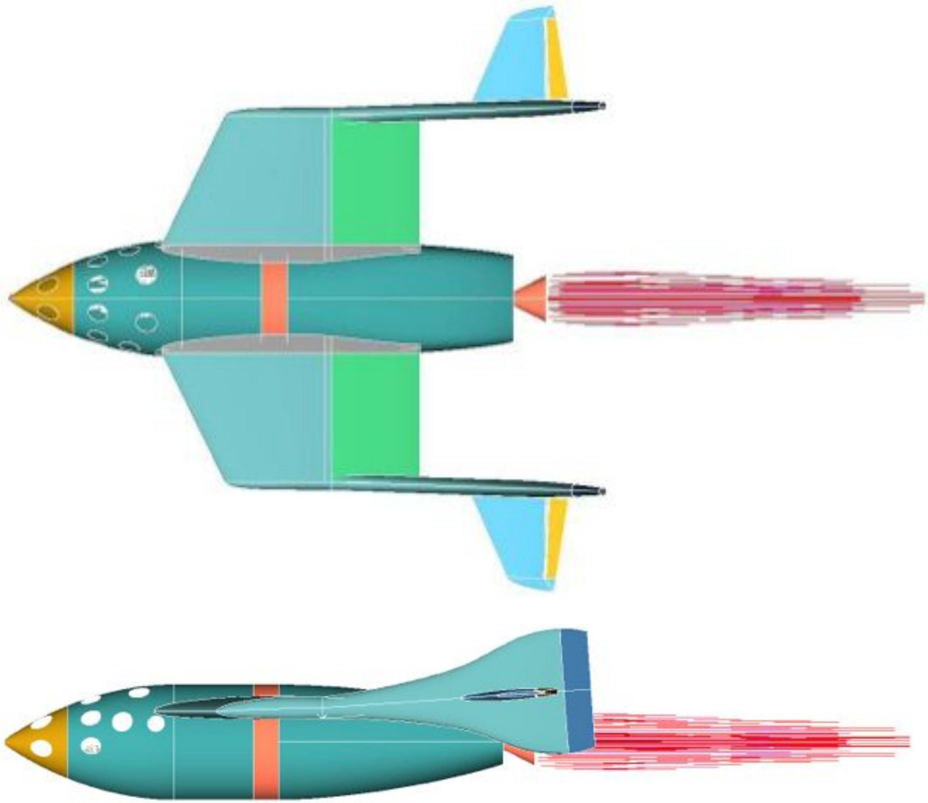
A new dedicated Launch Aircraft (Model 318) releases the Spaceship in level flight above 50,000 feet

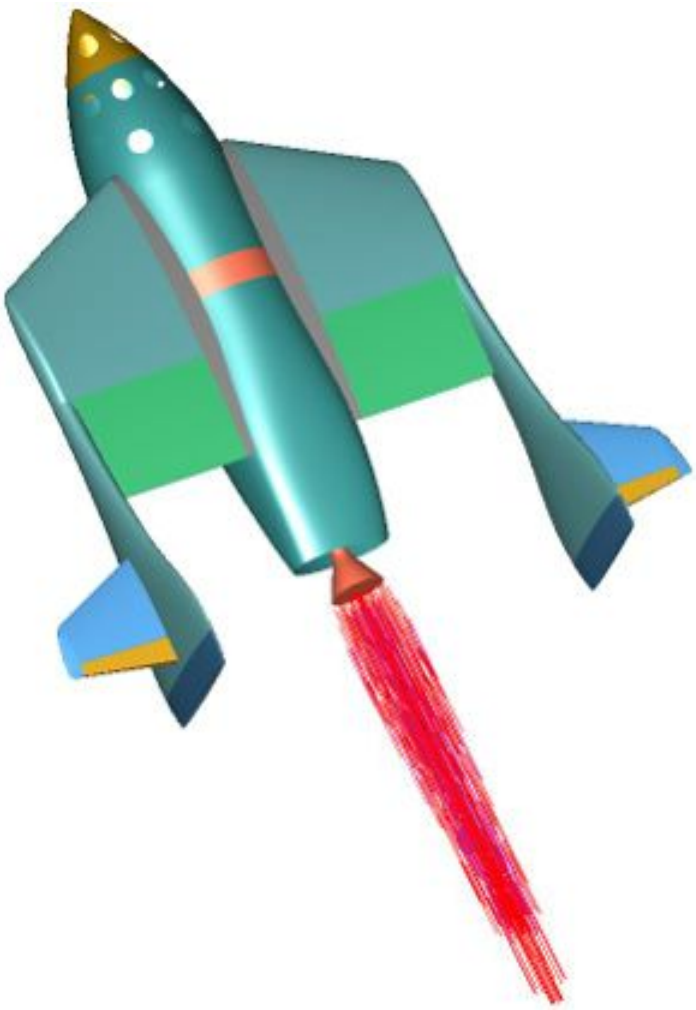
Launch Aircraft also functions as a Spaceship training platform and Spaceship systems development tool.



Boost phase is at low q - start high and go steep

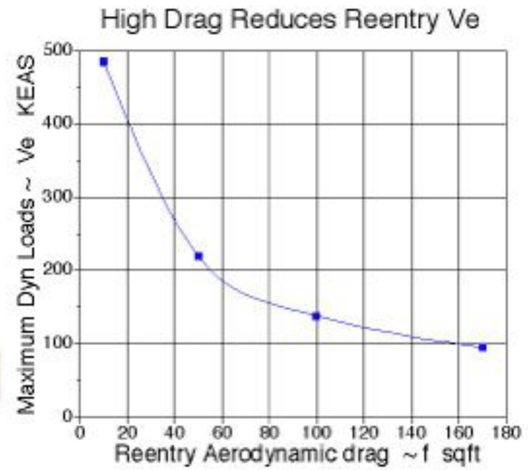
- After air launch, the spaceship glides clear, then ignites the rocket motor.
- Pull-up and accel to Mach 3+ vertical velocity.
- Low aero loads during boost due to high launch altitude.
- Burnout occurs within the atmosphere. Spaceship then coasts out of the atmosphere.
- Simple control system: elevons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

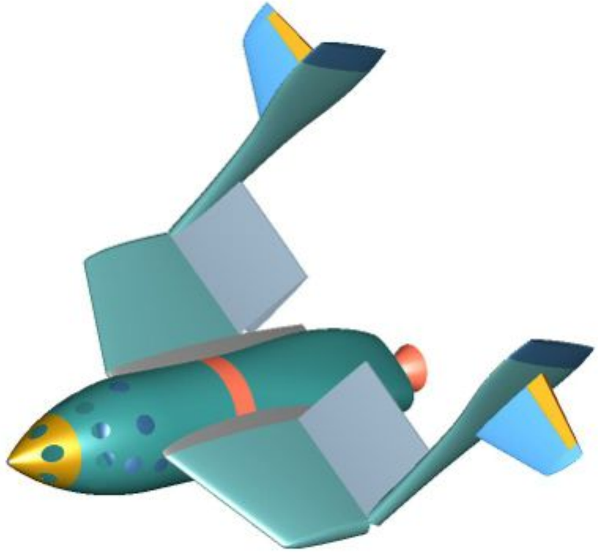




Atmospheric entry is carefree using single-mode, super stability

- 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).

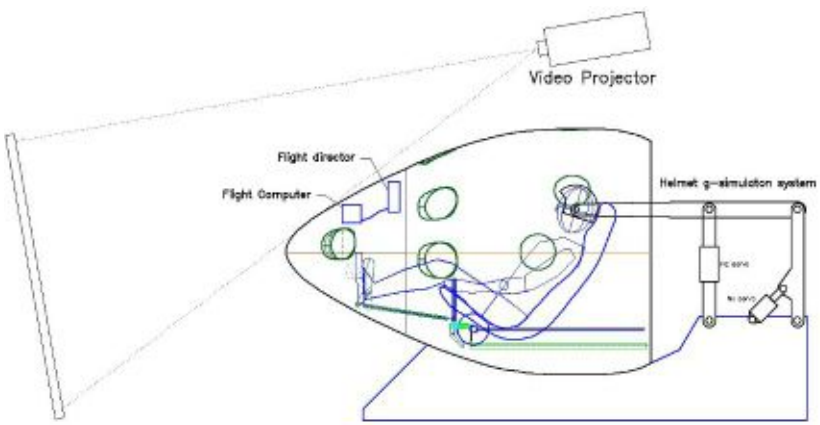


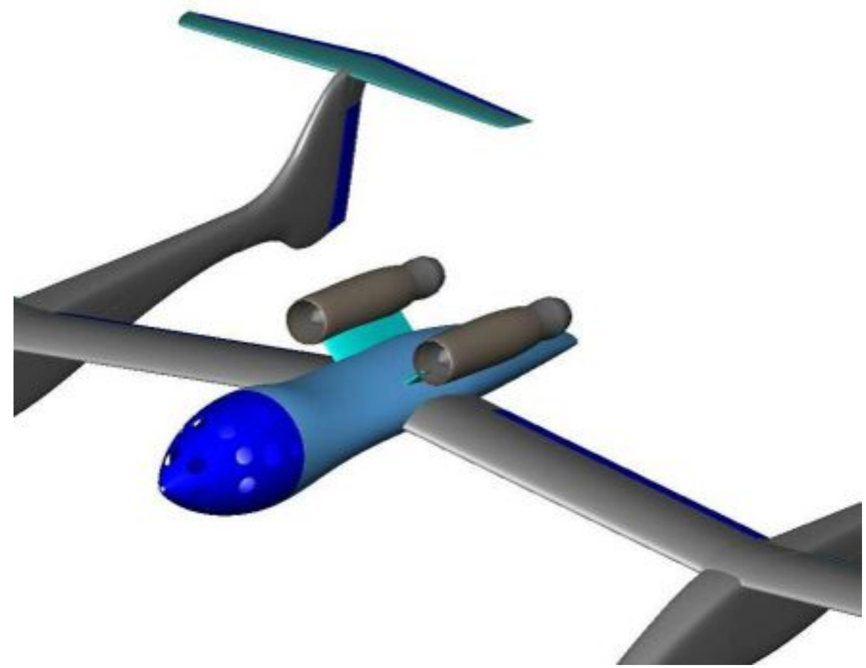


Pilot Training and Qualification

- 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

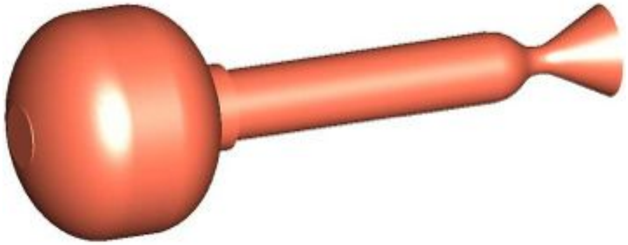
- Launch aircraft has SpaceShip cockpit
  - Identical: seats, windows, controls & avionics
  - Flight director commands pull-up for boost training
  - Zoom at low altitude allows 20 sec of zero-g
  - Descending windup turn duplicates reentry g profile
  - Spoilers and drag brakes use SpaceShip controls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

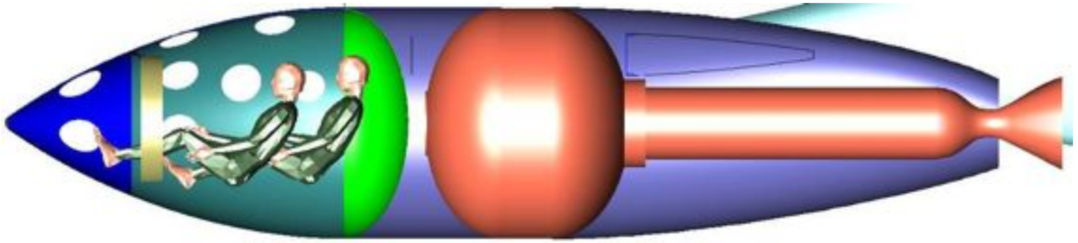




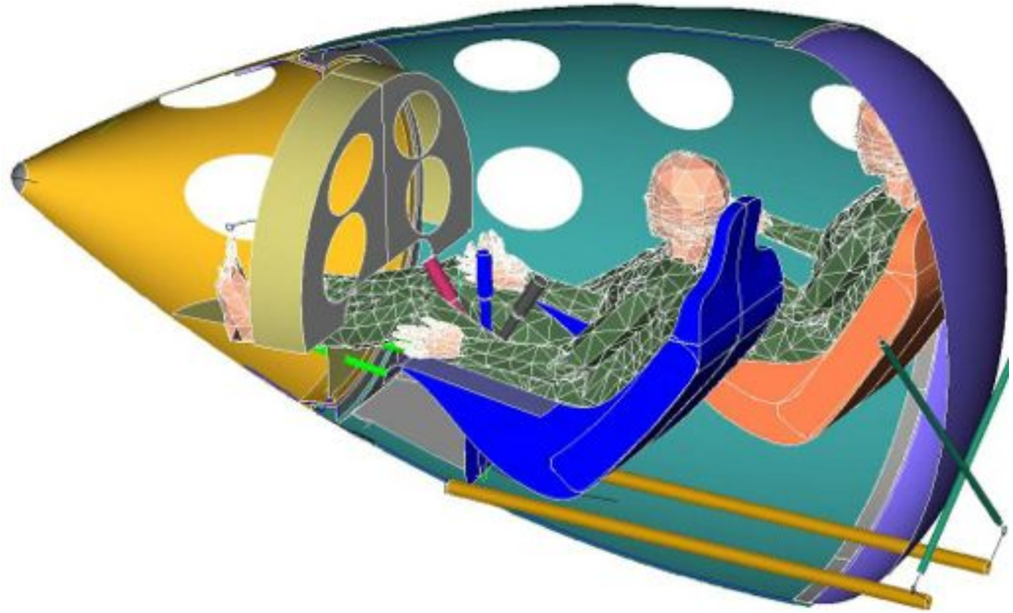
Integrated Hybrid Propulsion System
New Design - Breakthrough In Simplicity

- 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

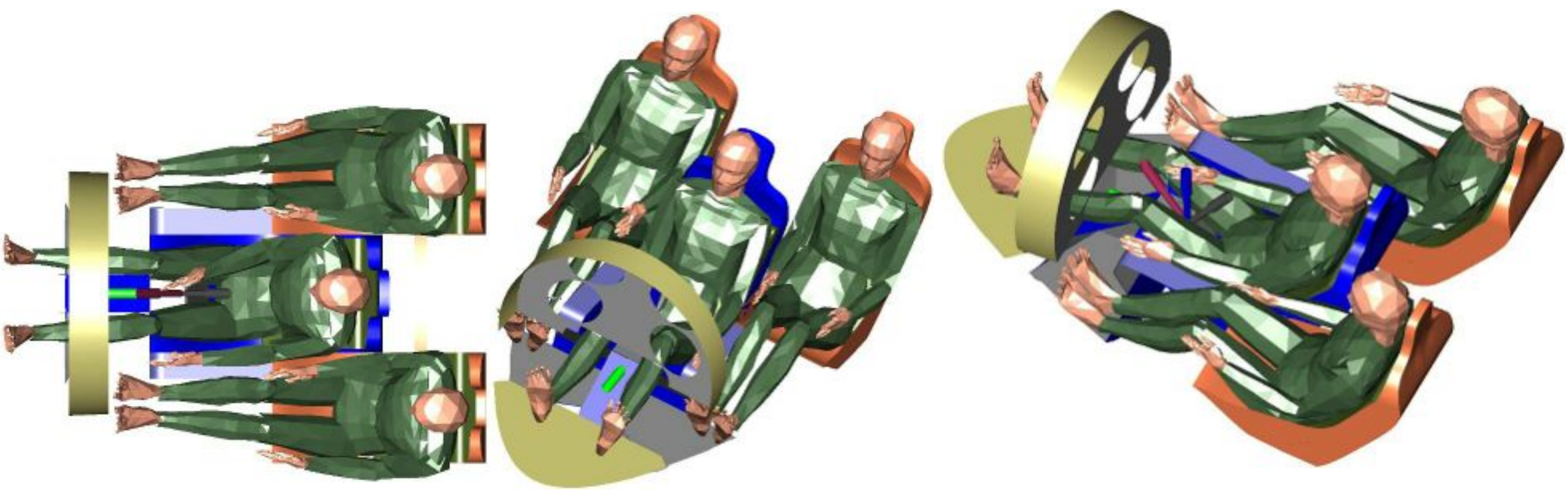




Seating and Crew Restraint



- 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

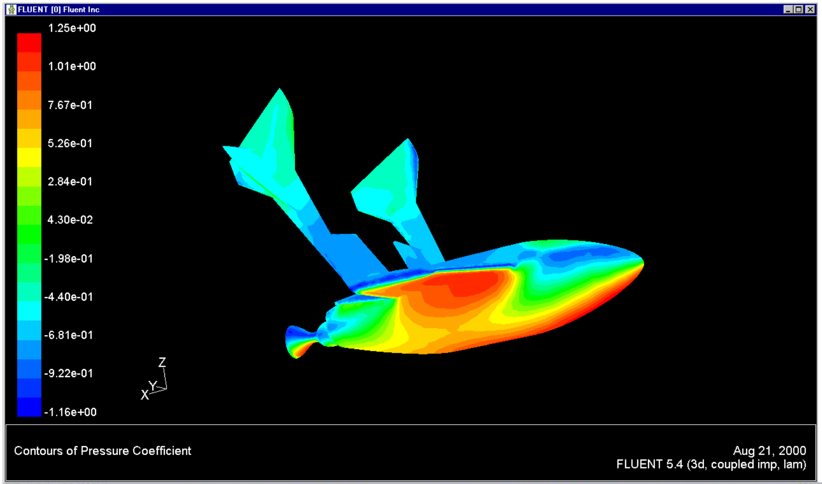


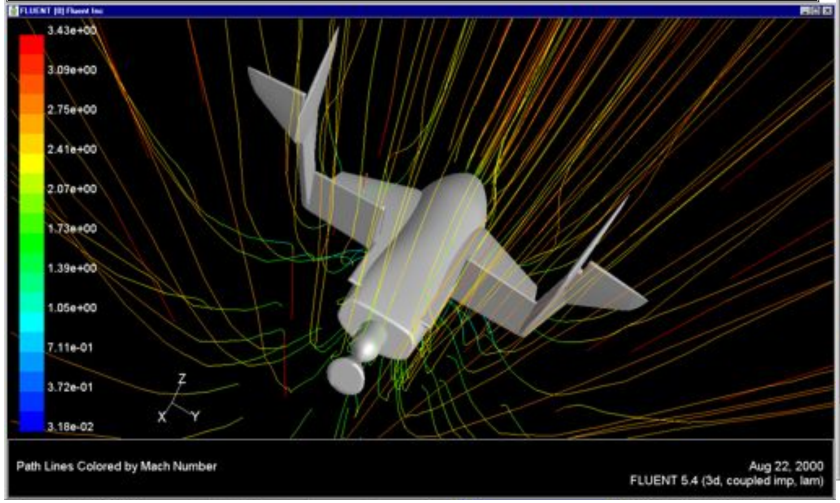
Avionics

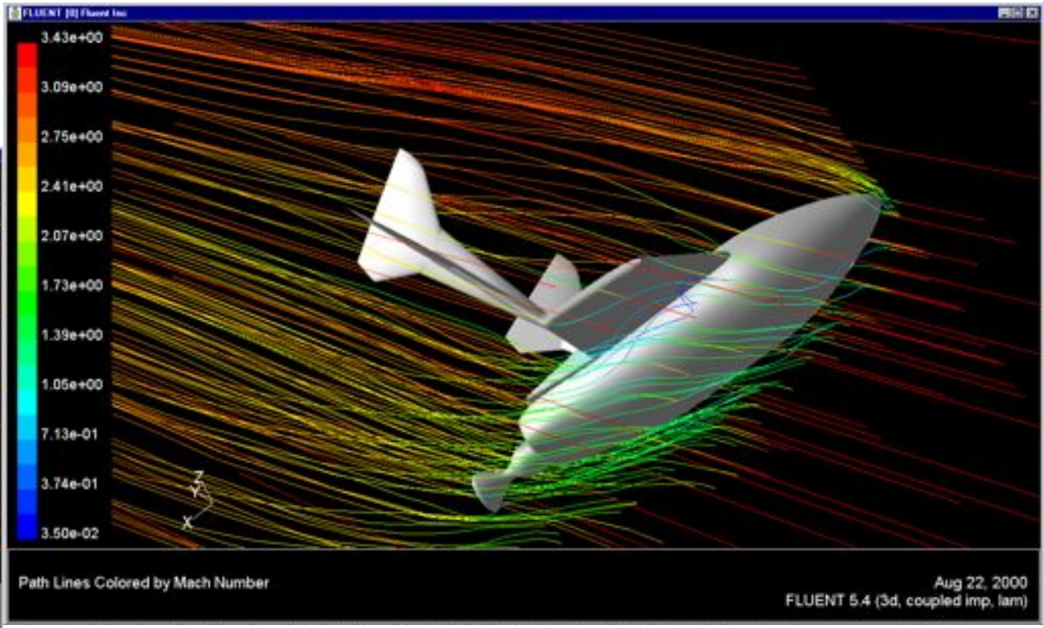
- Navigation/Flight Director
  - New unit, based on FunTech RacerView INS/GPS system, battery operated
  - Flight director provides boost steering commands for trajectory and to projected reentry location
  - Flight director provides approach steering commands for projected touchdown location
  - INS 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



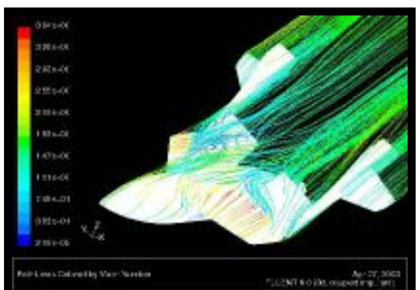


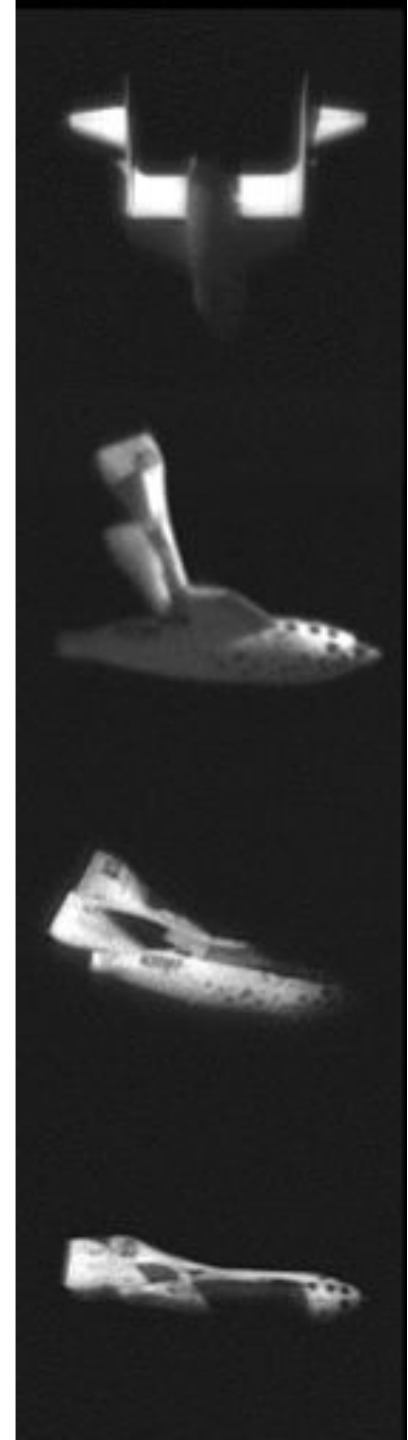


The Re-entry Feather
Immune to accidents caused by entry flight controls

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.

Flutter GVT

Window Damage Tolerance at 2x operating pressure (proof test at 3.5x)

ECS, CO2 scrubbing

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

Mac Faget and Buzz Aldrin

Cliff Robertson and some friends

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.