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Innovation Survival
Concept, Courage, and Change

W. David Schwaderer

W. David Schwaderer
MIT SDM Conference
10/19/2007
Innovation Survival
The Voyager Aircraft Startup Journey

Dick Rutan Speaking Engagements
Www.DickRutan.com
Agenda

• The Principals
• The Wet Napkin
• Test Plan Phase I
• Test Plan Phase II
• Plan Execution - The Flight
• Conclusion
The Principals

Dick Rutan
Pilot

Burt Rutan
Designer

Dick Rutan
“Obsessed” with flying
Decorated Aviation War Hero
Air Force “maverick”
Two Ejections
Retired from Air Force
Is The Right Stuff
Survives via micro
Likes aerobatics flying

Burt Rutan (Younger Brother)
“Obsessed” with airplane design
Youth Champion Model Airplane builder - No Kits
Prolific Airplane Designer, Least Cost, On toilet, 9/9/10
Founded Rutan Aircraft Factory (RAF)
No interest in mundane manufacturing/testing/“cust. base”
Flys ~one fun, interesting, educational design each year
Composites (~10X stronger than steel, rapid prototyping)
Avid EAA supporter
Has a macro

Jeana Yeager
Dick’s Girlfriend
Adventurous
95 lbs.

2.61 gallon/lb.
The Principals cont’d.

Aviation in itself is not inherently dangerous. But to an even greater degree than the sea, it is terribly unforgiving of any carelessness, incapacity or neglect.

- Captain A. G. Lamplugh

Experimental Aircraft can be safe. Fly safely - or - experiment, pick carefully.
<table>
<thead>
<tr>
<th>Roy Bailets</th>
<th>Kevin Furman</th>
<th>Brad Mottier</th>
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<tr>
<td>Richard Barrett</td>
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<td>Bob Brubaker</td>
<td>Kathy Hansen</td>
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<td>Mary Buckingham</td>
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<td>Bob Callender</td>
<td>Brian Hobbs</td>
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<td>Jim Johnson</td>
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<td>Dr. George Jutila</td>
<td>Cliff Robertson</td>
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<td>Martin Caskey</td>
<td>Sylvia Jutila</td>
<td>Walt Rogers</td>
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<td>Phil Clark</td>
<td>Ken Katz</td>
<td>Dave Ronenberg</td>
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<td>Sharon Cox</td>
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<td>John Roncz</td>
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<td>Judy Lindberg</td>
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<td>Ferg Fay</td>
<td>Glenn Maben</td>
<td>Irene Rutan</td>
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<td>Leslea Fay</td>
<td>Stan Magnuson</td>
<td>Pop Rutan</td>
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<td>Isabel Fortune</td>
<td>Walt Massengale</td>
<td>Nell Rutan</td>
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<tr>
<td>Gil Fortune</td>
<td>Dave Mayrose</td>
<td>Burt Rutan</td>
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<td>Dale Fox</td>
<td>Pete McEvoy</td>
<td>Tonya Rutan</td>
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<td>Billie Fox</td>
<td>Mike Melvill</td>
<td>Dan Sabovich</td>
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<tr>
<td>Gary Fox</td>
<td>Sally Melvill</td>
<td>Kelly Sandifer</td>
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<td>Wanda (Wolf) Fox</td>
<td>Steve Mendenhall</td>
<td>Jim Schoonmaker</td>
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<td>Mort Friedman</td>
<td>Milt Mersky</td>
<td>Darin Scines</td>
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<td>Fitz Fulton</td>
<td>Ken Modlin</td>
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<td>Mike Sedan</td>
<td>Doug Shane</td>
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<td>Dick Shane</td>
<td>Lana Shane</td>
<td>Allen Siebert</td>
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<td>Luan Siebert</td>
<td>Leonard Sieracki</td>
<td>Brent Silver</td>
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<td>Frank Smigielski</td>
<td>Terri Smith</td>
<td>Frank Tiff</td>
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<td>Terri Smith</td>
<td>Len Snelman</td>
<td>Marge Tiff</td>
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<td>Don Taylor</td>
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<td>Bonnie Tiff</td>
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<td>Margo Tiff</td>
<td>Flo VanBurkleo</td>
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<td>Larry Tonish</td>
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<td>Rich Wagoner</td>
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<td>Francis Yeager</td>
<td>Jean Yeager</td>
<td>Susan Whittington</td>
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<tr>
<td>Lee Yeager</td>
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</tbody>
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The Wet Napkin

Light & Slippery

Build Airframe – Sponsor $$$, Construction Contract
Test Phase I - Mission-adequate flying qualities &
   Aerodynamic range capability
Test Phase II - Install final components
Fly mission

Declare victory now?

No battle plan survives first contact with the enemy.

Field Marshall Helmuth von Moltke
Immediate Wet Napkin Plan Changes

February, 1981

Flying Wing

Not enough fuel capacity
Too light at flight’s end

March, 1981
# Phase I Wet Napkin Plan Changes

## Initial Assumption

Obtain Major Sponsor $$$

*They’ll beat a path to our door!*

## Reality

18 Months: No Interested Sponsor

*We were so naive.*

Bootstrap, grassroots funding.

---

### Dick

**Give it your best shot - we’re betting you -**

*R Tuck*

**Roy G. Tuck**

10617 NE 197th Street

Bothwell, WA  98011

**P.S. Don’t laugh - I don’t get lunch today**

～$2,000,000 Project

- $100 Donations
- Scrounging
- A Few Fabulous Sponsors
Phase I Wet Napkin Plan Changes *cont’d.*

<table>
<thead>
<tr>
<th>Initial Assumption</th>
<th>Reality</th>
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<tr>
<td>Obtain Major Sponsor $$$</td>
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<tr>
<td>(Beat a Path to the door)</td>
<td><em>We were so naive.</em></td>
</tr>
<tr>
<td></td>
<td>Bootstrap, grassroots funding.</td>
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<tr>
<td>Someone Will Build the Plane</td>
<td>Self-Built, Self-Taught + Industrial support</td>
</tr>
</tbody>
</table>

*Considerable on-the-spot engineering*

- TLAR
- SWAG
- Few formal drawings

Photo Credits: EAA - [http://www.youngeagles.org/airplanemonth/1206/](http://www.youngeagles.org/airplanemonth/1206/)

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Phase I Wet Napkin Plan Changes cont’d.

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<td><em>We were so naïve.</em> Bootstrap, grassroots funding.</td>
</tr>
<tr>
<td>Someone Will Build the Plane</td>
<td>Self-Built, Self-Taught + Industrial support</td>
</tr>
<tr>
<td>Cockpits Pressurized, No O₂ Required</td>
<td>Cockpits <em>Not</em> Pressurized =&gt; O₂ Required</td>
</tr>
<tr>
<td>(Heavy, Over-Pressurized Tanks); +3 days</td>
<td>(Heavy, Over-Pressurized Tanks); +3 days</td>
</tr>
<tr>
<td>Fly West East</td>
<td>Fly West <em>→</em> East, Bad Weather</td>
</tr>
<tr>
<td>Lots of Interior Room</td>
<td>Telephone booth sized <em>torture chamber</em></td>
</tr>
<tr>
<td></td>
<td>Physiological effects unknown</td>
</tr>
</tbody>
</table>

Phase I Nasty Surprises

Funding
Schedule
Pressure

Mysterious static electricity sparks, smoke, and fuel fumes
Mysterious fuel line arteriosclerosis => off-the-shelf motorcycle battery fumes

- One rudder to save weight (1 lb. => 3.5 lbs. fuel)
- Vertical tails marginal for straight flight
- Canards incorrectly designed => vortex generators, Roncz

Adverse Yaw and dihedral effects => Terrible turning when heavy

Oshkosh Flight => Radar, O₂ essential

Incredible noise in cockpit, negligible sleep
90 percent duty cycle (e.g. fuel transfers) => autopilot critical
Off center canopy => vertigo, rely on instruments

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Phase I Nasty Surprises cont’d.

**Define:** Voyager - A 17-compartment, sealed, flexible aerial fuel bladder containing 3.5 tons of explosive fuel surrounding two potential-incineration candidates.

> 82.5 knots => Constant Aeroelastic Threat

- Undamped oscillation (Burt)
- Low-frequency, high-amplitude divergent flutter mode (Dick)

Increase fuel weight => Increased speed => Unavoidable
Particularly dangerous during takeoffs and landing

**Dick**

- Feared Voyager
- Death Premonition

+- 35’ Wing Flapping before there is a structural consideration

**Band-Aid fix:**

- Raise Main Gear
- Lower front landing gear
- Fix failing front landing gear bolts

* A fundamentally unsafe aircraft
* A flying death-trap
* Fly it and retire it

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# Phase II Wet Napkin Plan Changes

<table>
<thead>
<tr>
<th><strong>Initial Assumption</strong></th>
<th><strong>Reality</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>New Plane Design =&gt; Proven, Off-the-shelf Engines</td>
<td>New-Design Rear Engine</td>
</tr>
<tr>
<td></td>
<td>(13 HP less eliminates ~2,000 lbs fuel)</td>
</tr>
<tr>
<td>Lightweight Wooden Gliding Propellers</td>
<td>Efficient Hartzell Metal Propellers</td>
</tr>
<tr>
<td></td>
<td>+70 lbs weight versus +3%-5% efficiency</td>
</tr>
<tr>
<td>Only 6 to 12 Months Total Required</td>
<td>72 Months Required</td>
</tr>
<tr>
<td>Nine or Ten Test Flights</td>
<td>~ 67 Flights before world flight</td>
</tr>
<tr>
<td></td>
<td>(landing gear designed for 10 smooth landings)</td>
</tr>
</tbody>
</table>
Phase II Nasty Surprises

Vandenberg Emergency Landing

Impossible Prop Pitch Control Motor Failure
Rear Engine Windmilling => Lethal Drag
Electric Prop Pitch Motors
Rated: 100° C, 9 Volts
Voyager: >150 °C, 28 Volts

Pitching problem increases with increasing weight
Uneven Paint Touchup Induced Canard Rudder Flutter
Electrical system full of gremlins and mysteries
Alternator failed => brush block slipped out of crimp joint
Landing Gear near failure
Lead Foul Sparkplugs => Use new Champion fine-wire iridium-tipped sparkplugs
Engineering cooling formulas gave 50% error at Voyager’s low speeds
Hearing loss is inevitable, altitude impedes taste and thirst

Unacceptable Wooden Propeller Manufacturing
Incorrect shape required rework
Thrown Wooden Prop forces emergency landing
Hartzell Metal Propeller Replacement Chosen
Modify Engines to support hydraulic oil prop control motors

Saving the program requires emergency assistance from NBAA sponsors.

Dick can’t sleep inside Voyager, feels he must fly whenever above 82.5 knots
Fatigue reduces IQ and body’s O₂ absorption ability

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December 14, 1986

Edwards tower, this is Voyager 1. Sir, we are ready to go.

Voyager 1, this is Edwards tower. ATC clears Voyager 1 from Edwards Air Force Base to Edwards Airforce Base via flight plan route. Maintain 8,000. Cleared for takeoff, and Godspeck.
Takeoff Surprises

Structural Weight: 934 lbs.
Gross $W_{to}$: 9,694.5 lbs (10.38 X 934)

Non-Fuel - 2,683 lbs

Added Fuel - 354 pounds
Takeoff Fuel Weight: 7,011.5 pounds (1,029 gallons)
Fuel Fraction: 72.3%

Fuel weight warped plane
Canopy cover would not fit without pounding

Heavier forward boom tanks
=> Wing moment forward of fulcrum
=> Airplane flying down
=> Wing tips dragged before liftoff

I reached up and grabbed the stick and started easing back. I said to myself, Dick, if you’ve ever been smooth in your life, you better be smooth right now, because this is the big one.

2 Minute, 14 Second takeoff
14,200’ distance (a record), 800 feet remaining

15% Additional weight (8430 lbs + 1264 lbs) => >2X takeoff distance
+20-21% (8430 lbs + 1684 lbs.) => No liftoff

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Lost Winglets => 6% Additional Drag ( ~1,500 Fewer Miles Range)

- Flown 354 hours, six immediate emergency landings
- Flight plan is 225 hours, heading over Pacific
- December => Worst weather
- There is no route. [no certitude]
- Path updates every six hours

**Path Priorities**

1. Wind
2. Weather
3. Politically sensitive areas.
Engine Out

42 Gallon Header Tank has 9 gallons, Remaining 1200 Miles require 28 Gallons. => Find (28 - 9) == 19 Gallons

Immediate Rear Engine Starvation => Windmilling & Slow Descending Spiral
Vandenberg Forced Landing => Front engine can’t pull plane when rear engine windmilling
Three hands to get front engine oil pressure up to un-feather prop
Front engine starts; low altitude + light weight => front engine pulls plane
Over-rotation => fuel flows to back engine + Windmilling => Back Engine Starts
Swap Electric Fuel Pumps, transfer fuel to header tank
December 23, 1984

It was so amazing to us because I didn’t know anybody would even be around.

I thought maybe “Flying Magazine” or the EAA would be there with a reporter, take a picture, make some notes for a story. And when I saw all those people [40,000], it was absolutely unbelievable.

Takeoff fuel: 7,011.5 lbs - 1,029 gallons
Remaining fuel: 106.4 lbs - 18.3 gallons (1.52% left, 98.48% used or leaked)
There were no rules on Voyager, no rules. We broke all the rules, a lot of rules that were published for airplanes. The media and Edwards were deceived into thinking that we believed that we could do this. Now we had to… is good, this is high confidence, it’s very safe, or they wouldn’t let us use their runway. … We knew it was a very high risk that it wouldn’t make the flight.

Burt was amazed and he told me later. He says “Dick, it’s a funny thing that I told you how the airplane was going to be designed and what it would do. I was always amazed that you or nobody ever asked me to prove it mathematically.”

And, it didn’t even dawn on me. If my brother said that it could be done, I knew absolutely sure that it could be.

Voyager Flight (cont’d)

[Bruce Evans] There is no way that airplane should have made it and it should never fly again.

[Dick Rutan] We’ve got to get it back here [Mojave].

[Bruce Evans] All right, then take off, make one left turn, and just come back home. Don’t touch a thing. Don’t even turn on a lot of electronics. And then don’t fly it anymore. It was built to go 20 flights and you went 68. …

[Dick Rutan] After we landed, I noticed the coolant seal had failed completely.
Smithsonian Museum

Photo Credit: http://www.youngeagles.org/airplanemonth/1206/photos/Gallery-23-down.jpg
Device versus Product

Can you always take a scale-up shortcut from device to product?

The Voyager was a highly compromised device.

Burt Rutan design-inspired device to product attempts:
- Raytheon ® Beechcraft ® StarShip ®
- Visionaire ® Corp Vantage ®
- Adam Aircraft® A500 ® /A700 ®

**Subjective Verdict**

Success

**Financial Failure (Evergreen)**

Bankruptcy 1.26¢/$Debt*

Jury out, schedule slip

*Passing all the FAA tests is much harder than I would have guessed… It is 20 times harder than just building the airplane.*

– Rick Adam, Adam Aircraft

The proof-of-concept designer’s fault?

No…it’s just a big world.

Start liking it.

http://www.avweb.com/avwebflash/11_18b/briefs/189691-1.html - cited 01/24/2007 as:

$35 million in debt. In 2003, Matt Eller of Eviation bought the company's assets for $441,000

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Some Closing Observations

- Rust, reality, entropy, and physical laws (including gravity) never sleep.
- Unless you are personally omniscient, have a good team with varied backgrounds.
- Of 100 people on the ground and two in the air, only 102 are essential.
- Genuine bootstrap startups are often harrowing, threadbare deprivation-experiences.
- Don’t expect people to share your passions. Maybe somebody’s wrong.
- Spectators do not win; if you want to win, show up to compete.
- Correctly timed agility and audacity help, boldness is in short supply.
- Got a good design? Sell it yourself mano-a-mano, Boston Beer style - very educational…
- It ain’t over ‘til it’s over - Yogi Berra.
- Surprising “impossible” things can happen - some good, some bad.
- Define success carefully and know what you want before starting, if possible.
- Sometimes pragmatism is better than purity, sometimes it isn’t.
- Sometimes inexpensive commodity components are good, sometimes they aren’t.
- Devices and products are very different; Voyager was a highly compromised device.

All those Voyager design surprises?

One must learn by doing the thing; for though you think you know it, you have no certainty until you try. - Sophocles
Finally, Remember Luck’s Role

I would rather be lucky than good. - Silicon Valley Maxim

- Front Engine Mounts broke when wooden propeller failed
- Efficient Rear engine versus +2,000 lbs fuel (and no lift-off?)
- Added 354 lbs fuel over W_to recommendations, 18.3 remained on landing
- If I knew we’d have that much [takeoff] climb, I would have loaded up another few hundred pounds of fuel [400 lbs more fuel => No liftoff]
- Fuel line arteriosclerosis, electrical system gremlins, blown bulbs and pumps
- Landing gear bolts were failing
- John Roncz’s canard and metal prop design, global insect inventory and 68 bug streaks
- Tires at 3,200 PSI versus 1,800 PSI
- Unwanted Starlight Scope from Lt. White
- Weather corridors closed - e.g. Typhoon Marge & Low Pressure Area
- Typhoon Marge => ~30 free Knots
- Missed Delay Request Message off Africa
- Noticed fuel flowing backwards just in time
- Mt. Cameroon near miss
- Mobil Synthetic Oil possibly saved rear engine
- 90° Bank Recovery
- Restarted front engine just in time and it flew plane, enabling rear engine to start
- Engineered for 20 flights, flown 69
- Leaking coolant seal held until landing, completely failed on next, final flight to Mojave
Simplistic Naiveté’s Role

As always, victory finds a hundred fathers, but defeat is an orphan.

- Count Galeazzo Ciano, 1942
Simplistic Naiveté’s Role
Thank You

Cleared for takeoff, and Godspeed