

# CST Newsletter

Volume 3, Issue 1

January, 2003

*Welcome to this issue of the CST Newsletter*

**Included in this issue:**

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## December 2002 Meeting

**Billy Roeseler**



Ladislav Janda watches as Billy Roeseler flies the X Plane simulator.  
Photo: Rich Harman

Kris Guerquin and Ladislav Janda were there when Sergei Barmichev and I arrived around 11 am. Rich and Karen Harman had a nice spread for lunch. Rich hooked up the joy stick so we could play with X Plane. He flew a couple of flights using ZFW = 2200, GW = 5500, Isp = 210 sec with 9000 lbs thrust, got between 215 and 260k depending on Cdo, initial pull-up, and pilot skill. When we increased propellant mass fraction from .6 to .7, we got to 360K ft, which is above 100 km. We hit M = 3.6 at 137k on our best flight. L/D was between 1 and 6 during most of the pull-up, which was held below 2 g. Kris had the S4V on display, said it weighed 2.9 kg today with flight controls and servos. Bruce Watson called in from Eastern Washington and talked with Rich for 20 min. He reported progress with using TurboCAD.

Chris Erickson came in around 12 noon, and Rich called the meeting to order. Chris expressed concern about all the thermal, biological, and chemical environments we would encounter during our flight operations. He has experience with cadmium and molybdenum with

thermal cracking and leaking, even explosions. Janda felt Bruce should lead the CAD effort, and we talked at length about the need for parametrics, CAD, financial backing, and avionics. It seems we are doing for \$10M what it would cost Boeing a billion or NASA ten billion to do. We will need to work very smart, even cut some corners like Dave Penney and others have done in getting flight vehicles together at low cost.

Rich and Sergei expressed concern about the weight and balance, and Wm agreed to provide some updates. Kris showed us an alternate vehicle design (see page 7) with more aspect ratio and frontal area and spherical tanks. Wm estimated the OEW of Kris's design to be around 2000 lbs, compared to 1000 lbs for our minimum "point of departure" vehicle. We talked at length about the need for more aspect ratio, pitch authority, and empty weight. Kris wondered about power for the subsystems, wondered if hydraulics would be lighter than electrical actuation. Can we use the high pressure gas to drive a hydraulic pump or generator?

The team seemed to feel that the S4V avionics would weigh around 200 g plus 300 g for 1500 mah of batteries at 6v. Sergei plans fabric hinges on the carrier aircraft, and he left some photos of the 16 ft wing span with spars and ribs in place. Rich plans to update our web page. Kris and Rich will work to improve the strength and stiffness of our flight control actuators based on a minimum flight speed of 40 kts and a maximum of 700 kts.

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## December 2002 Meeting

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Chris described the avionics baseline for the S4V, which will weigh around 30 lbs, and we discussed the need for an air data system. The USB port will provide sufficient bandwidth, and we will be using a Motorola CPU. The GPS will give us some idea of our speed every second or so, may be accurate to a couple of knots. We also talked about using a \$200 police radar to supplement the S4V telemetry.

Sergei has been consulting with his RC buddies including Phillip, who has lots of experience with very large models. We talked about the paint job that will enhance visibility and the need for various tracking telescopes and other devices. Rich has a 2.4 GHz video link we could use for better visual cues during flights of the S4V. We agreed to practice at the RC model field with any tracking device we may want to use when it is our turn.

We went over the business plan for the first ten years of commercial operation, and Karen asked some good questions about our legal structure and plans. Chris will talk with Ed Wright, and Sergei will talk with his billionaire Microsoft friend about funding. We talked about Teledesic and the launch business in general. Chris will continue to report his expenses as Astro Technologies, and we talked about Dave Penny, Patrick Booth, and SMU.

Kris mentioned at the meeting that we should use our high pressure inert gas to power a generator to conserve battery power. That sounded to me like a good idea. We may also need a small turbopump to push LOX thru a heat exchanger to pressurize our LOX tank. If we need 240 SCF of He2 to pressurize our fuel tank, we should be able to get 1 hp from a small turbopump using energy as the Helium expands from 200 atm to 20 atm. I believe we were thinking in terms of a 12 v electrical system, using 30 ah (360 w-hr) of battery capacity, which would weigh around 15 lbs. Our power requirements are around  $1000\text{w} \times .2 \text{ hr} = 200 \text{ w-hr}$ . Energy obtained from the high pressure gas could supply 50% of our total electrical requirements. Adding a hydraulic system would no doubt add cost and weight, and our flight control power requirements are small enough to get by without hydraulics.

The other thing that came up at the meeting was the actuator stiffness requirement. For low speeds below 200 KEAS, simple cables to the control stick should suffice, but when we get up to 400 KEAS, we may need more stiffness. This has already become an issue on our S4V, and it will be an issue on our X-Prize Vehicle (XPV)

as we get into detail design. If the flap chord is 10 inches and the span is 20 inches, the max force may be  $3 \text{ psi} \times 200 = 600 \text{ lbs}$ . The max hinge moment may be  $600 \times 3 = 1800 \text{ in lbs}$ , which would require 600 lb cable force on a 3 inch horn.

Rich had to leave for work at 2:30, and the rest of us were out of there by 3 pm. Many thanks to Karen and Rich for their great hospitality.

Here is the weight and balance (see below) I promised at the December 29th CST meeting. It shows a CG shift from 187 full to 156 empty, which is probably unacceptable, as suggested by Kris. I will move some mass around to see if we can make it work.

In the process of putting this update together, I found some earlier work dated 1998, which compares our weights to those of the Long EZ and the X-15. Then in 1999 I put together a talk for the MOF with more detailed weight and balance, including 90 lb landing gear and 60 lb avionics. There was a personal note from Scott Crossfield indicating our fuselage weight was optimistic and suggesting the landing gear alone may weigh 300 lbs. When I get back from Roatan, I will compare our weights with the Lancair IV-P, which is as close to our design as any current aircraft. She has an empty weight of 2200 lbs, a useful load of 1000 lbs. She is optimized for 1000 mile range above 350 mph, with her twin turbo TSIO-550E engine at 350 hp.

	Mass	CG	mx
<b>Lox Tank</b>	200	244	48800
<b>Fuel Tank</b>	100	136	13600
<b>He Tanks</b>	50	172	8600
<b>Cabin</b>	120	70	8400
<b>Fuselage</b>	50	200	10000
<b>Wing</b>	120	250	30000
<b>Gear</b>	80	180	14400
<b>Propulsion</b>	80	300	24000
<b>Tail</b>	50	300	15000
<b>Flight Control</b>	50	300	15000
<b>Subsystems</b>	100	200	20000
<b>OWE</b>	1000	207.8	207800
<b>Payload</b>	600	70	42000
<b>Zero Fuel Weight</b>	1600	156.125	249800
<b>Fuel</b>	800	136	108800
<b>Oxidizer</b>	1600	244	390400
<b>Gross Weight</b>	4000	187.25	749000

# Folded Pintle Injector

## K. Mark Caviezel, Denver, CO

I've started work on a 10,000 lb thrust engine. I'd like to work at a larger scale, but at my day job I have access to a lathe and a mill just large enough to work with ~12" diameter, which can make about a 10,000 lb thrust engine.

Right now, I have no-where close to all the engineering done, but am most interested in a real, comprehensive manufacturing strategy that won't break the bank. At my day job, I've been wearing a machinist's hat more and more and subsequently have been learning a lot about mechanical fabrication through the process of actually doing it. I'm getting pretty darn good at making stuff out of 304 stainless, which is a probably a good material to make the 10k engine out of.

Rough schedule is, static test December 2003 at Mojave Test area. I was back there for the December firing and it felt great to be out there. So far, I have made an 11" diameter carbon steel mock up of a 'folded pintle' injector. I need to interface it to a couple garden hoses to run some qualitative flow impingement tests, and quantitative water flow tests before proceeding with a stainless version of this.

I am using the term 'folded pintle' on my own. I don't know if similar phraseology is used elsewhere to describe something else.

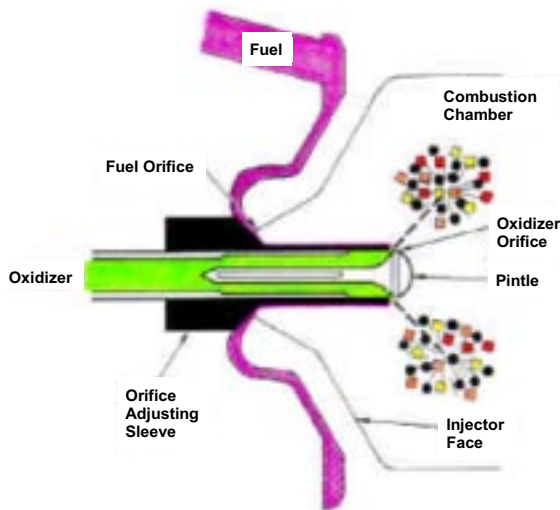


Figure 1 Pintle Injector Concept (Continuous Gap Concept, Fixed Thrust or Throttling Designs)  
Ref. AIAA 2000-3871 "TRW Pintle Engine Heritage and Performance Characteristics"

Point of reference, a 'normal pintle' (such as in the Tom Mueller-designed Kimbo engine or the Delta II 2nd

stage engine. Also see figure 1.) is made from only two parts, a big 'washer' and a plate with a pintle. The plate is the Liquid Oxygen (LOX) dome; the fuel is fed down the center of the pintle. The LOX comes out between the annular gap between the 'washer' and the pintle as a hollow cylindrical sheet, going straight aft from the injector. The fuel goes down the interior of the pintle where it is shot out laterally as a fan. Most of the fuel intersects and mixes with the oxidizer, but with proper design, some fuel makes it all the way to the chamber wall where it serves as coolant. Now, if this were a hypergolic propellant engine, "when the sheet hits the fan" all hell breaks loose. Other propellant combinations require an ignitor.

Ok, the 'folded pintle' has a similar arrangement for the oxidizer- it is shot out in a hollow cylindrical sheet down the long axis of the engine. The fuel is injected from outside the LOX through a 45 degree beveled slot. With this arrangement, a regenerative engine can take fuel from the combustion chamber jacket and shoot it directly into the combustion chamber without some weird, ugly plumbing.



Figure 2 Here is the assembled injector. 11.5 inch OD  
Photo: K. Mark Caviezel

The 'spots' are 4 weld-plugged tool holes used to attach the plate to the lathe bolt-up plate. And 8 welded in dowel pins. The three plates of the injector are aligned and attached by the dowel pins. The LOX gap is 0.110" and the fuel is 0.075" for injection velocity of 25 and 20 meters/second respectively.

(Continued on page 4)

# Folded Pintle Injector

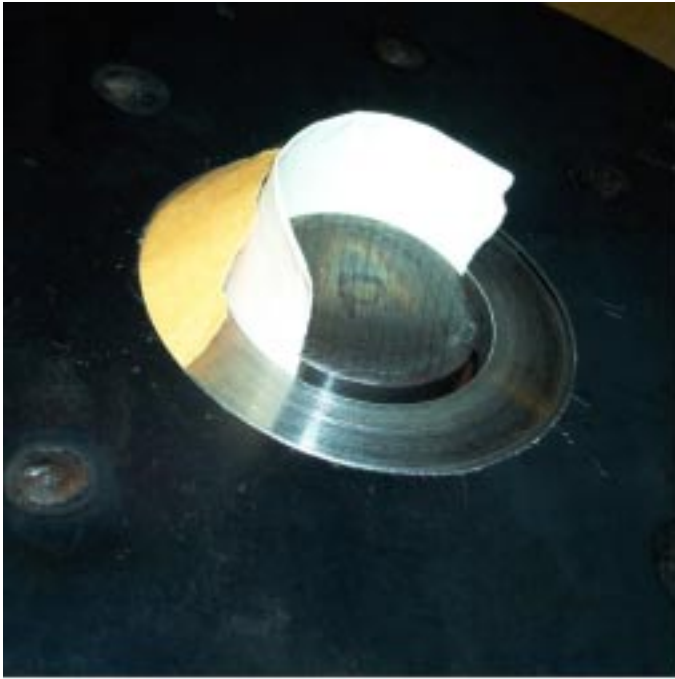


Figure 3 This is a close up of the 'folded pintle' the yellowish scrap of junk mail shows the path of the fuel. The white paper shows the path of the LOX.  
 Photo: K. Mark Caviezel

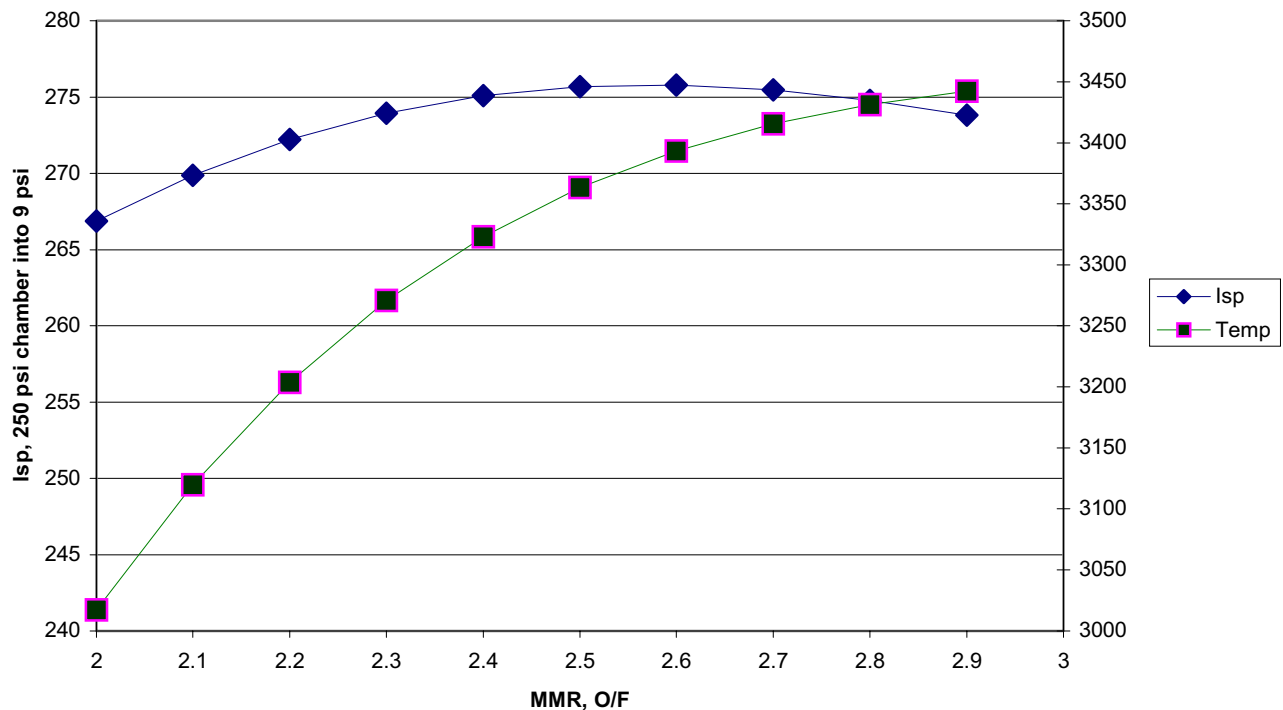
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The fuel is cryogenic propane (propane that is chilled to around 90K). Propane and propylene have freezing points less than 90K, so they are candidate fuels that could be stored isothermally in a common bulkhead tank with LOX. (of course with LOX on the other side of the bulkhead). Design chamber pressure 250 psi, injector about 12" diameter.

This is a concept I have been toying around with for a long time, and have finally gotten off the dime to look into it. The idea is that, on the pad, you set up a heat exchanger to pre-chill the propane - density and cooling capacity goes up. This could be used for a launch vehicle, or X-Prize application, or something that would be space storable. I'm no expert on spacecraft thermal issues but it seems possible that a spacecraft, particularly one that didn't loiter in Low Earth Orbit (LEO) could have thermal treatment to keep the propulsion system at 90K. LOX/hydrogen (hydrogen has a natural boiling point of 20K and LOX a natural boiling point of 90K with a freezing temperature of 55K) seems to have some issues for long term storage in space. N2O4/hydrazine are storable at room temp, but freeze at modest temps (I

*(Continued on page 5)*

**LOX/propane performance**



# Folded Pintle Injector

*(Continued from page 4)*

think about 0 F) LOX/cryogenic propane has good density, good specific impulse and can 'hang out' just fine on a spacecraft that is heading outward on a spaceflight. For the delta-V required for a Pluto circulization, LOX/ cryogenic propane is a very strong candidate. Theoretical Isp is about 390 seconds, making it a little better than LOX/kerosene and significantly better than conventional storable hypergols.

At my day job, we will be starting a phase one SBIR to look at LOX/propylene for all the same reasons I spell out for LOX/cryogenic propane.

## 10k LOX/Propane Steel Injector Design Parameters

- Pc .....250 psia
- Thrust at 9 psi exit ..... 10,000 lbf
- Mixture Ratio, O/F.....2.2 to 1
- Theoretical Isp @ 9 psi.....272 sec
- Actual Isp, Main Flow, 94% efficiency.....256 sec
- Isp if no contribution from BLC .....277 sec
- BLC.....0.4
- Required Propellant, Mains .....39.1 lb/sec
- Total Fuel .....43.97 lbs/sec
- LOX = 26.9 lb/sec = 12.19063 kg/sec = 10.57 liters/sec = 0.010575 m<sup>3</sup>/sec
- Propane, main = 12.2 lb/sec = 5.541193 kg/sec = 7.60 liters/sec = 0.007602 m<sup>3</sup>/sec
- Propane, BLC = 4.9 lb/sec = 2.216477 kg/sec = 3.04 liters/sec = 0.003041 m<sup>3</sup>/sec

- Cf, SE, from lookup chart..... 1.47
- Throat Area..... 27.27 in<sup>2</sup>
- Throat Diameter ..... 5.89 in

## Regenerative Cooled Folded Pintle Injector

- Injector diameter ..... 1.784 in.
- Pintle diameter ..... 1.792 in.
- LOX temperature..... 89K
- Propane temperature ..... 270K
- Temperature rise ..... 181K heat adsorbed
- LOX density ..... 1.15 10.57 liters/sec MAIN
- LOX vp ..... 12.2 psi
- Propane density, at ini ..... 0.59 9.40 liters/sec MAIN
- Propane vp ..... 50.8 psi
- 3.76 liters/sec BLC
- LOX injection velocity ..... 25 m/sec
- LOX injection area ..... 0.00042 m<sup>2</sup> (0.656 in<sup>2</sup>)
- LOX gap ..... 0.110 inch
- LOX gap OD on "B" part ..... 2.011 inches (OD of LOX gap is ID of "B" part hole)
- "e distance" ..... 0.54
- "alpha" (90 degree is co-axial) .... 45
- "f distance" ..... 0.54 inch
- Fuel injection velocity..... 20 m/sec
- Fuel MAIN injection area..... 0.0005 m<sup>2</sup> (0.728 in<sup>2</sup>)
- Fuel annulus ID..... 3.091 inches
- Fuel slot w/r/t itself ..... 0.075
- Fuel slot (lateral) ..... 0.053
- Fuel slot OD ..... 3.198 inches (this is ID

## 250 PSI Chamber Expanded to 9 psi

O/F	Isp to 9 psi	Isp to vac	T <sub>c</sub> , K	Cr	Gamma, chamber		epsilon
2	266.9	295.9	3017	1.46	1.236		4.4
2.1	269.9	299.7	3120	1.46	1.231		4.6
2.2	272.2	302.8	3204	1.47	1.227		4.6
2.3	273.9	305.3	3271	1.47	1.224	epsilon	4.7
2.4	275.1	307.1	3323	1.48	1.222		4.8
2.5	275.7	308.4	3363	1.48	1.219		4.9
2.6	275.8	309.1	3393	1.49	1.218		5.0
2.7	275.5	309.3	3416	1.49	1.216		5.1
2.8	274.8	308.9	3431	1.50	1.215	epsilon	5.2
2.9	273.8	308.1	3442	1.50	1.214		5.2

## S4V Carrier Vehicle

X Plane model by Rich Harman. Model construction by Sergei Barmichev.

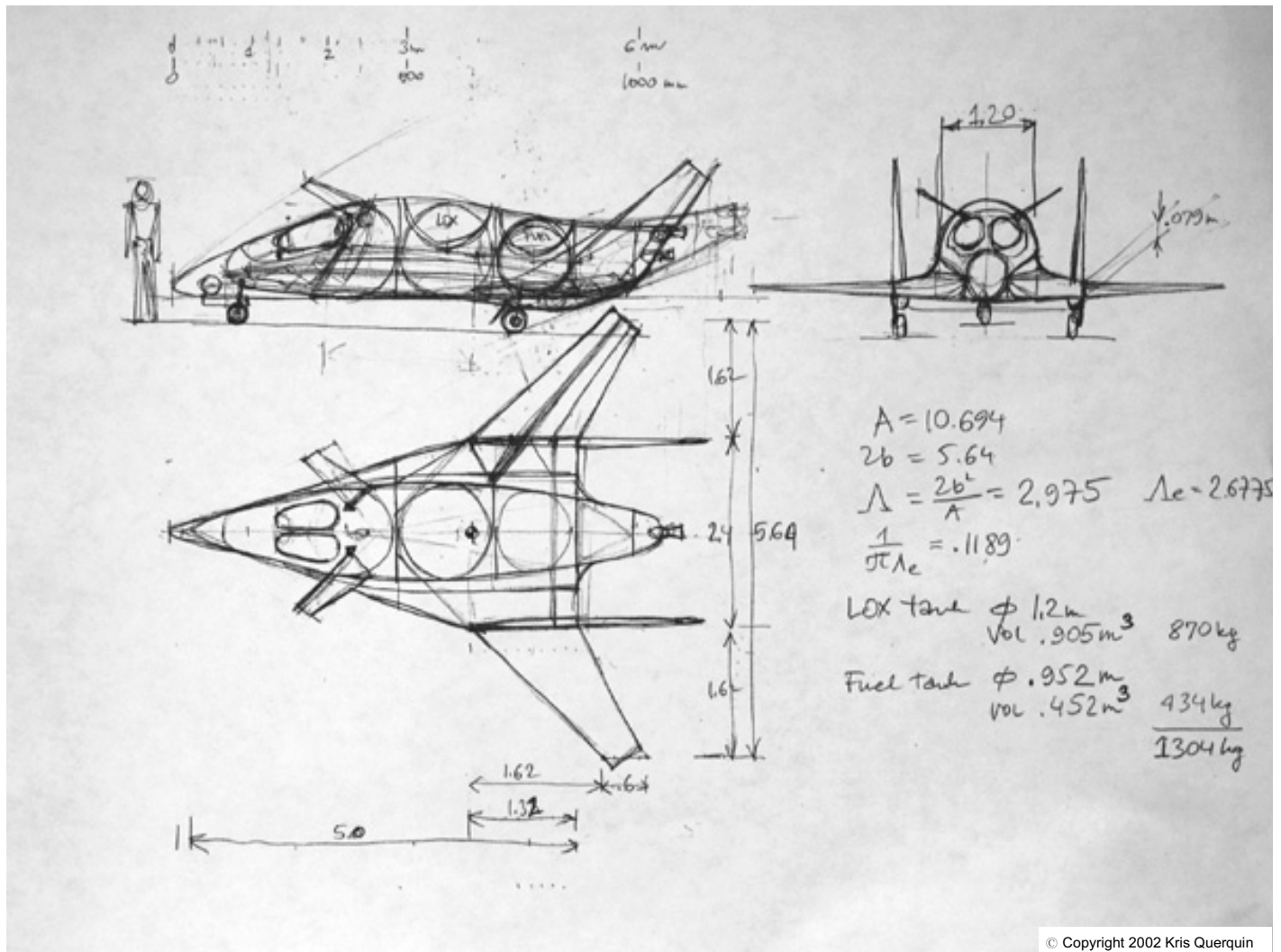


Clockwise from top: 3 different views of the S4V Carrier RC Vehicle taken from X Plane simulation. 2 different views of the construction of the S4V Carrier RC wings being constructed by Sergei Barmichev

All photos by Rich Harman.

# X-Prize Concept Vehicle

By Kris Guerquin



*Editors note:* This is an alternate concept for an X-Prize vehicle that Kris Guerquin developed about the same time that the group was developing our official CST XPV that the S4V represents.



Sergei Barmichev and Kris Guerquin at December 2002 meeting deep in discussion.  
Photo: Rich Harman

# S4V Vehicle Progress

Photos by Rich Harman



Kris Guerquin and Ladisiav Janda work on the almost completed S4V.



A view from the rear where the HyperTEK hybrid engine will be (see the June, 2001 issue of the CST Newsletter for details on the HyperTEK). Ladisiav Janda and Kris Guerquin.



Kris Guerquin attaching the cover to the S4V.



Interior view of the S4V with the top cover removed.

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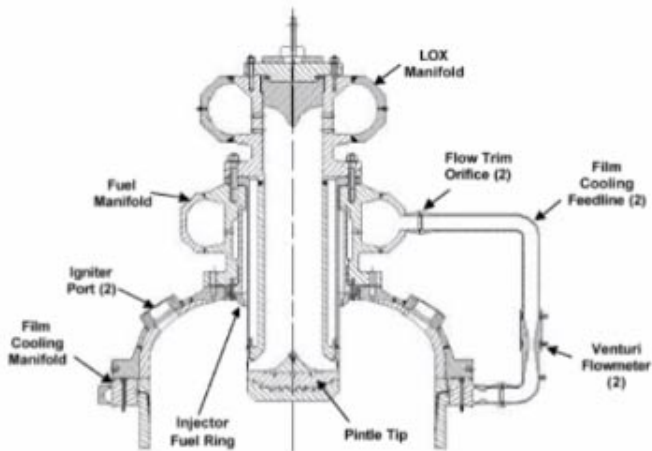
The primary goal of the Canyon Space Team is to support low cost, private, human access to space (sub-orbital, semi-ballistic flight) including research and development.

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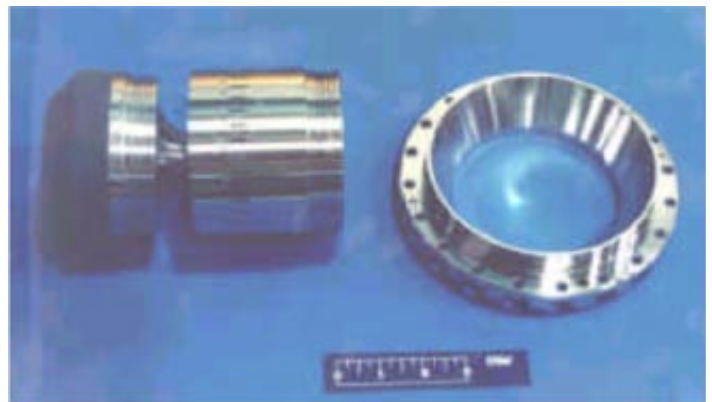
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Injector Assembly With Film Cooling



Pintle Tip, Oxidizer Orifice Ring and Fuel Gap Ring from I6K LOX/LH2 Engine

Ref. AIAA 2000-3871 "TRW Pintle Engine Heritage and Performance Characteristics"