# Horus project

*L4 Document package*

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CAR 975 L3
Tripoli 12025 L2

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## Revision table

| Revision | Date | Reason and description |
|---|---|---|
| A | January 2, 2011 | Original document |
| B | January 13, 2011 | New section – General construction details |
| | | Modification to the booster section |
| | | Add information to the recovery section |
| | | Add information to the Performance / motor section |
| C | January 14, 2011 | Modification to the fin dimensions |
| | | Add flutter analysis |
| D | January 27, 2011 | Correction to Fins construction details |
| E | January 29, 2011 | Motor retention, shear pins and drag separation calculation |
| F | February 4, 2011 | Drag separation of the upper section and rocket weight correction (motor performance) |
| G | March 5, 2011 | New fin flutter calculation, add 2 layers of CF |
| H | April 17, 2011 | Construction corrections |
| I | June 15, 2011 | Change electric diagram, and use switch to shunt the e-matches |
| J | June 26, 2011 | Add a missing 5cm tube on the ebay ! |

# Documentation Package

## General Construction details

Booster section

- 2 layers of 6oz fiberglass with West Epoxy will be applied on the tube to make it stronger. Even if for the first flight the maximum speed will be 282 m/s (0.85 Mach) and by PML specification their tubes can withstand speed up to 0.85 Mach without fiberglass. Having the rocket fibre glassed, we can assume a strength improvement of 50% so the tube will be able to withstand a speed of 1,2 Mach.
- All centering and bulkhead are linked together with 3 threaded rods
- 5 centering are epoxied on the motor tube and fillets are done on both sides to increase the strength. Those 5 rings will transfer the engine force to the rocket.
- The motor retainer chosen is the Aeropack 98mm. The motor retainer is attached to the lower centering with 12 8-32 Stainless Cap screws and threaded inserts.

Fins

- The fins are epoxied on the motor tube with Aeropoxy PR2032 and the join is reinforced with carbon fibre. The outside of the motor casing cannot be hotter than 200°C (as per Tripoli certification). The phenolic tube is providing isolation, the motor is burning for less than 5 seconds, not enough time to transmit a lot of heat to the epoxy, than the rocket is decelerating to reach apogee, in this phase the motor is already cooling and less stress is apply on the fins. Aeropoxy and carbon fibre were choose because they can support over 200°F.
- Extra strong material, G10 1/8”, with 2 layers of carbon fibre plus a tip to tip carbon fibre will be used to increase the resistance to fin fluttering. See Fin Section for analysis.
- Epoxy fillets are applied on the outside tubes and the fins to reinforce the bound with the rocket.

Coupler

- The coupler is reinforce with 1 layer of 6oz fiberglass plus a layer of carbon fibre inside the coupler, to help the epoxy bind the fiberglass and the coupler, a balloon is inflated inside the coupler, putting pressure on the assembly.
- The bulkhead that will host the U-bolt is doubled with a G-10 bulkhead and a layer of epoxy on the outside.

Drogue tube

- 2 layers of 6oz fiberglass are applied to reinforce the tube to make it stronger.

Main parachute section

- 2 layers of 6oz fiberglass are applied to reinforce the tube to make it stronger.

Electronic bay

- The electronic bay is reinforce with 2 layers of 6oz carbon fibre inside the coupler
- The bulkheads that will host the U-bolt are reinforced with a layer of epoxy to make it stronger and make it easier to clean.

Epoxy

- The epoxy use for temperature sensible location will be Aeropoxy PR2032 and hardener PH3630.
- The epoxy use in this project will be the West Epoxy (105) and hardener (205).
- JB Weld will be used for high temperature section, like on motor tube.

## Design limitation

Under the stress of the lift off the main parachute section and drogue section (airframe) are the weakest point of this design. The choice of using fiberglass instead of carbon fibre will limit the use of the rocket under Mach 1,2.

In the recovery system, the weakest link is the U-bolt, this why all bulkheads on which U-bolts are attached are doubled on the inside with a G10 bulkhead to increase the strength of the plywood and washers are present on both side to distribute the charges.

# Materials lists

## Motor section

- 1X 63,5cm PML fiberglass wrapped 15,316cm phenolic tube
- 3X custom fins of 0,125" G10
- 4X centering rings  0.5"  - Plywood 14,859cm to 10,211cm
- 1X Motor mount Tube PML 4" phenolic tube 70,5cm
- 1X Motor retainer 98mm, Aero-pack
- 1X PML coupler 98mm, 27cm – Reinforce inside with 2 layers (1fiberglass (6oz) and 1 Carbon fibre (6oz))
- 4X Hexa bolt ¼" x 20 lock knot
- 1X bulkhead 0,5" – Plywood 14,401cm – Reinforce on the outside with a layer of epoxy
- 1X bulkhead 1/8" – G10 14,895cm
- 1X centering 1/8" – G10 14,895cm to 10,211cm
- 1X 5/16" U-bolt
- 4X 5/16" Hexa-bolt lock for  the U-Bolt
- 2X 5/16" washer
- 1X plat for the U-Bolt
- 3X threaded rods ¼"-20 x 77cm
- 6X Hexa-bolt ¼" - 20
- 2X Launch button large (1515)
- 12X 8-32 Stainless Cap Screws

## Drogue section

- 1X 5 cm PML fiberglass wrapped 15,316cm phenolic tube
- 1X 58,5cm PML fiberglass wrapped 15,316cm phenolic tube
- 1X Cert 3 – Drogue parachute by SkyAngle
- 1X Nomex blanket
- 1X Kevlar sleeve 2" x 30"
- 3X Quick link stainless steel 1400lbs
- 1X Tubular nylon strap 3/4" x 35', 15Kn

## Main chute section

- 1X 107 cm PML fiberglass wrapped 15,316cm phenolic tube
- 1X Cert 3 – Xlarge parachute by SkyAngle
- 1X Nomex blanket
- 1X Kevlar sleeve 2" x 30"
- 3X Quick link stainless steel 1400lbs
- 1X Tubular nylon strap 3/4" x 40', 15Kn

## Electronic bay

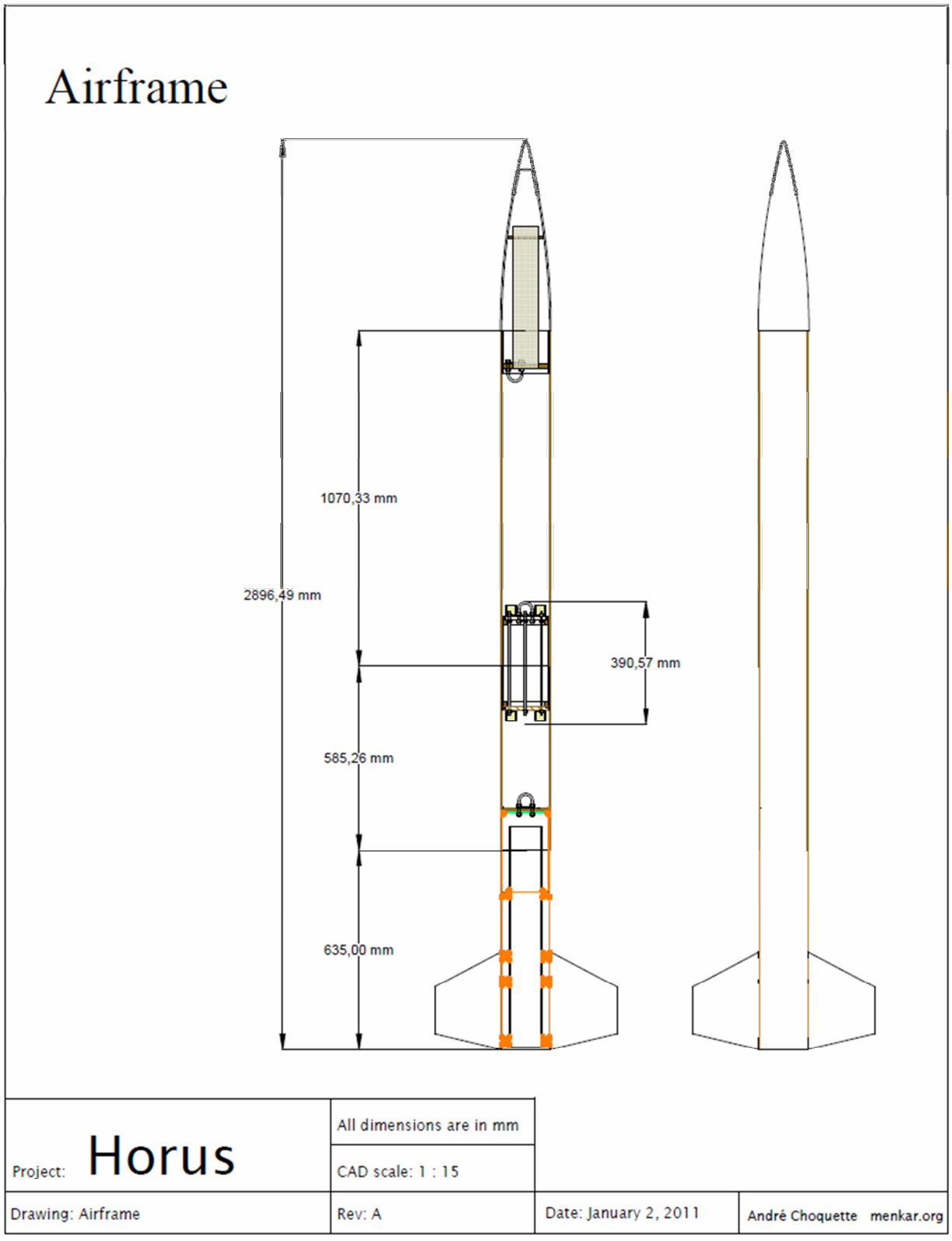
- 1X 30 cm PML phenolic coupler 148mm – Reinforce inside with 2 layer of fiberglass (6oz)
- 2X bulkhead 0,5” – Plywood 14,401cm – Reinforce on the outside with a layer of Epoxy (West)
- 2X U-bolt  5/16”
- 8X Hexa-bolt lock for the U-bolt
- 4X washer
- 2X plat for the U-Bolt
- 3X ¼” x 20 rod , 32,6cm
- 4X PVC end cap ¾”
- 2X Seal rings 0,5” – Plywood 14,401cm
- 8X #6-32 screws to secure Main and Drogue section to the electronic bay

## Nose cone

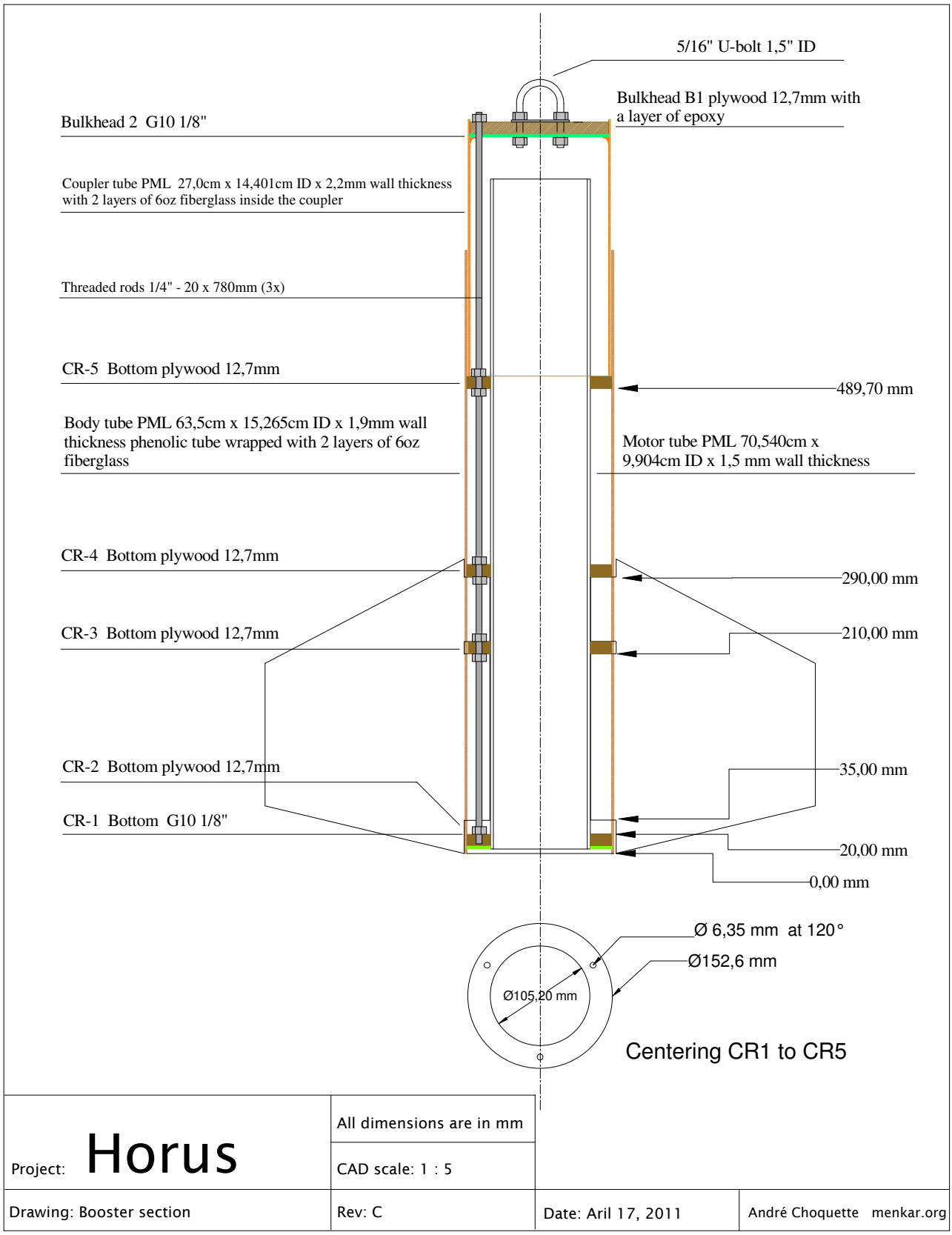
- PML Fiberglass nose cone FNC-6.0 length 60,960 cm, diameter 15.494 cm
- 1X centering 1/4" – Plywood 11,47cm to 7,95cm
- 1X centering ½” – Plywood 14,16cm to 7,95cm
- 1X bulkhead 1/8” – G10 9,66cm
- 1X 45,0cm PML phenolic tube for the GPS transmitter
- 1X 5/16” U-bolt
- 4X 5/16” Hexa-bolt lock for  the U-Bolt
- 2X 5/16” washer
- 1X plat for the U-Bolt

## Drawing

### Drawing 1 – General Airframe presentation

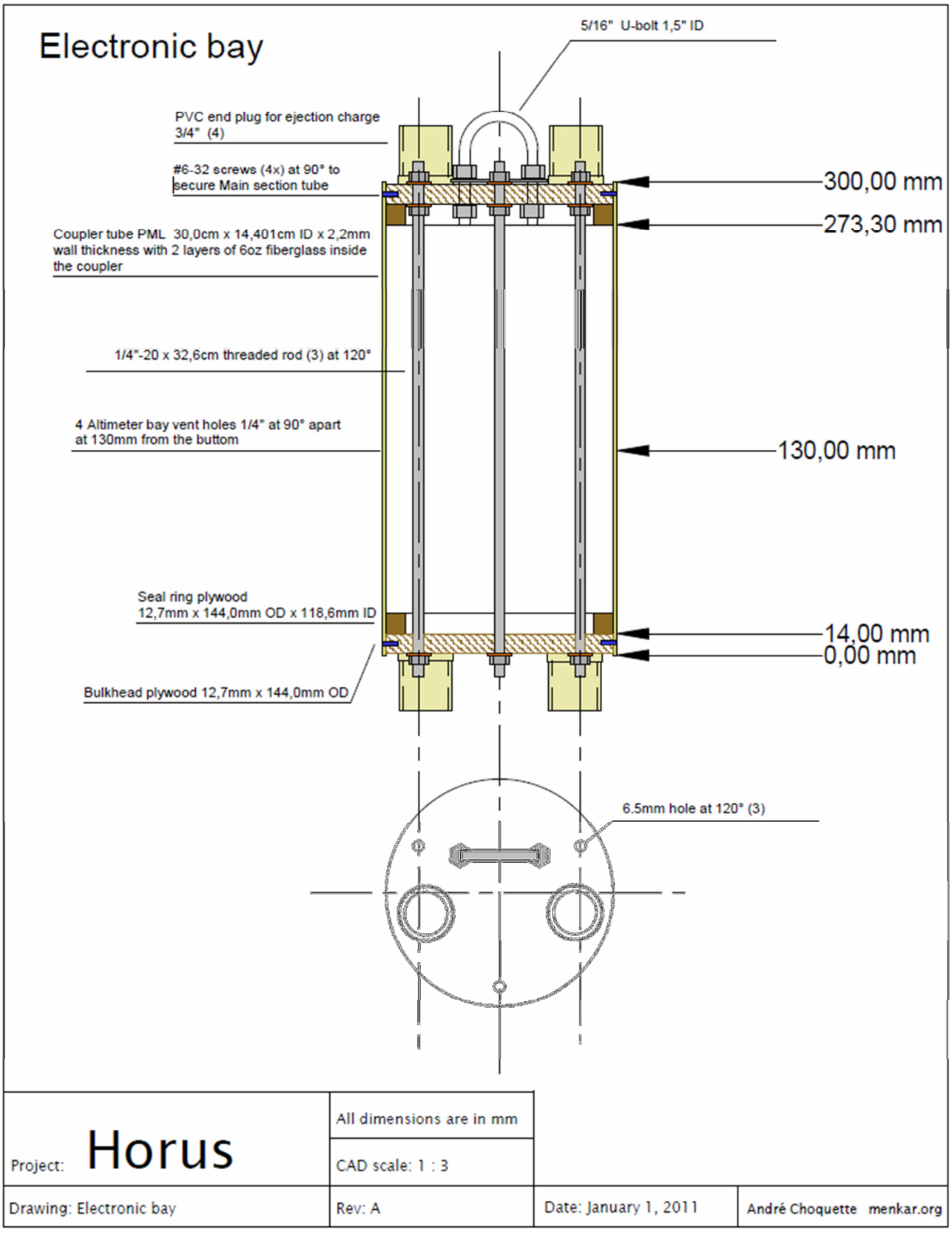


## Drawing 2 – Motor section

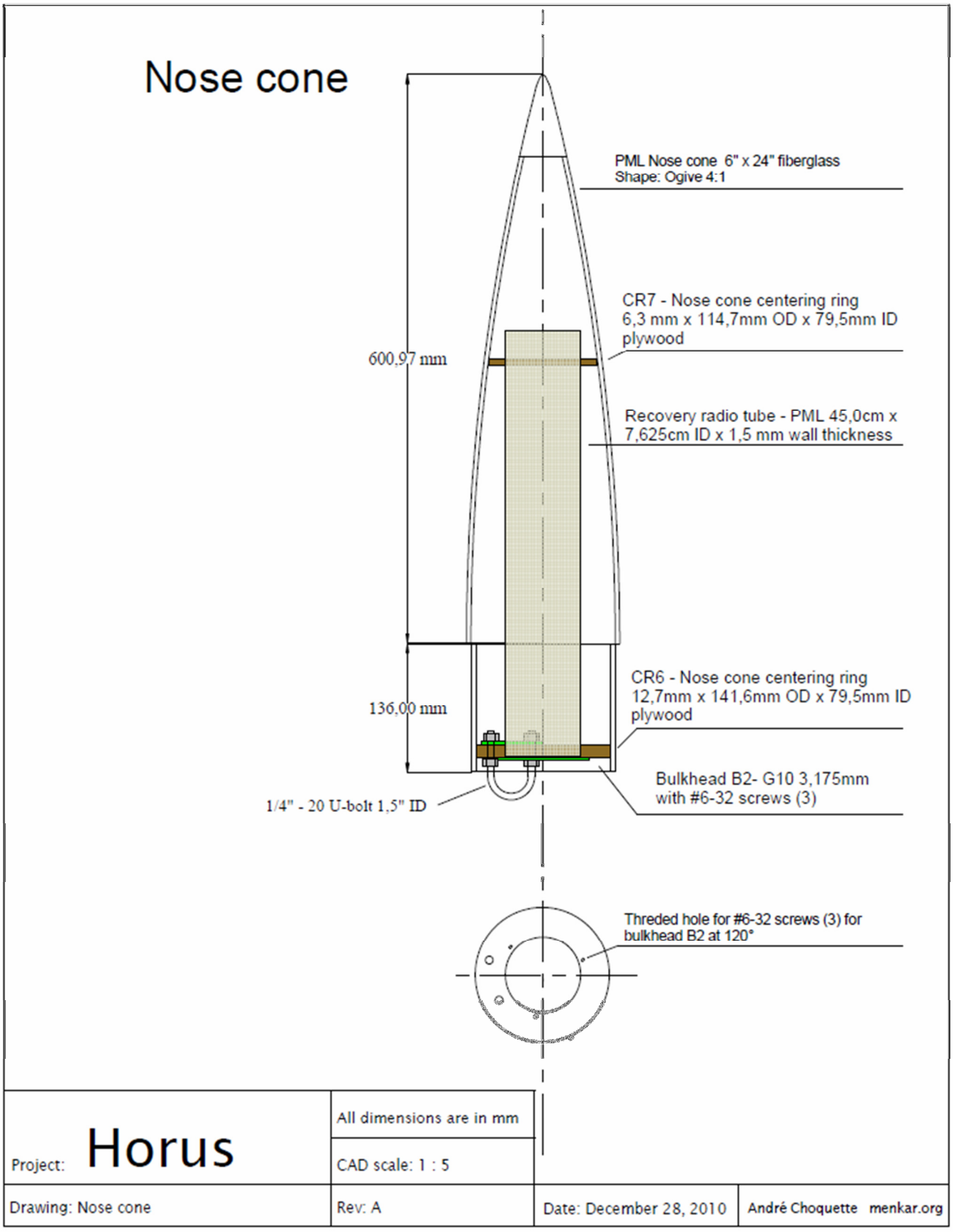



| | | | |
|---|---|---|---|
| Project: Horus | All dimensions are in mm<br>CAD scale: 1 : 5 | | |
| Drawing: Booster section | Rev: C | Date: Aril 17, 2011 | André Choquette menkar.org |

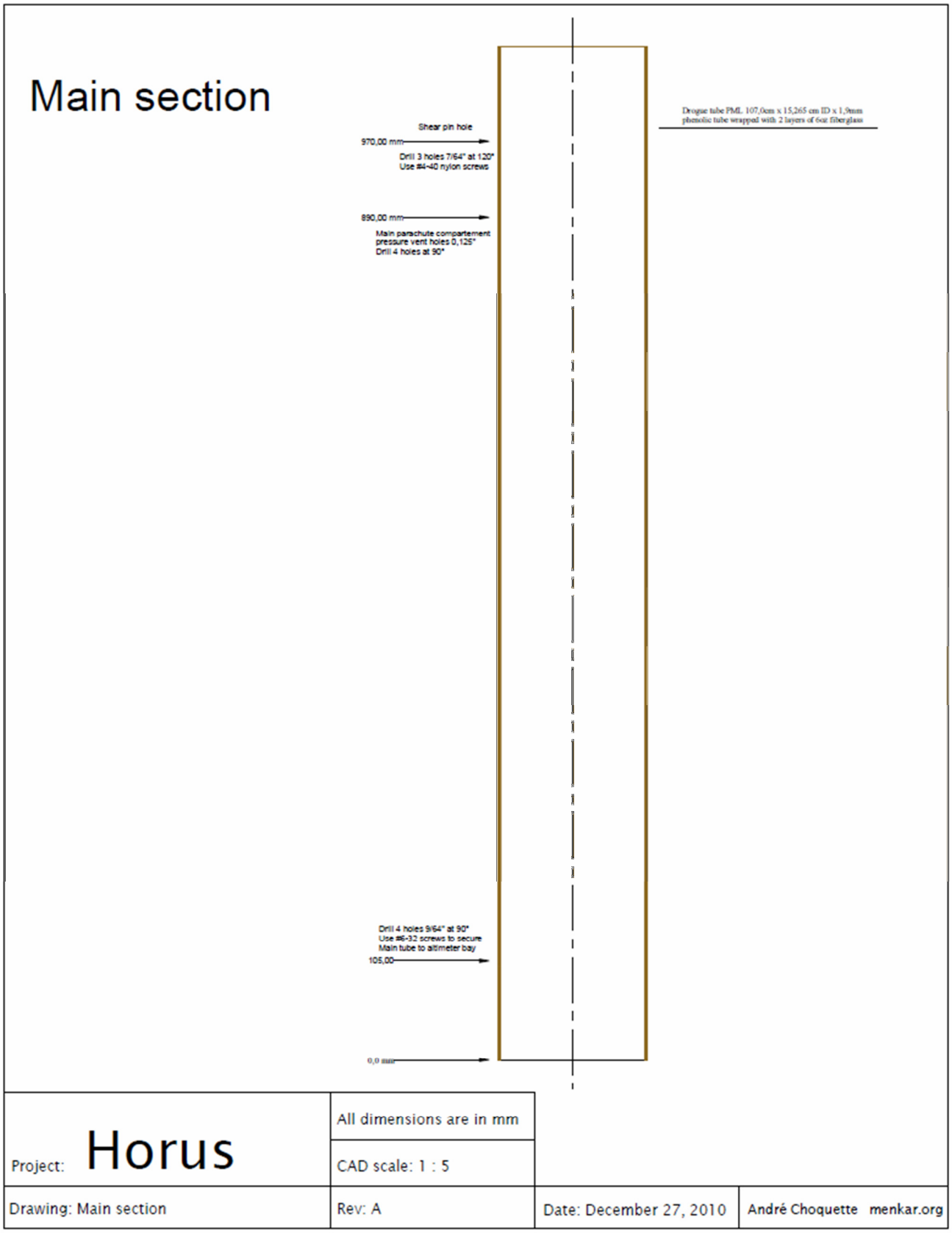
## Drawing 3 – Electronic bay



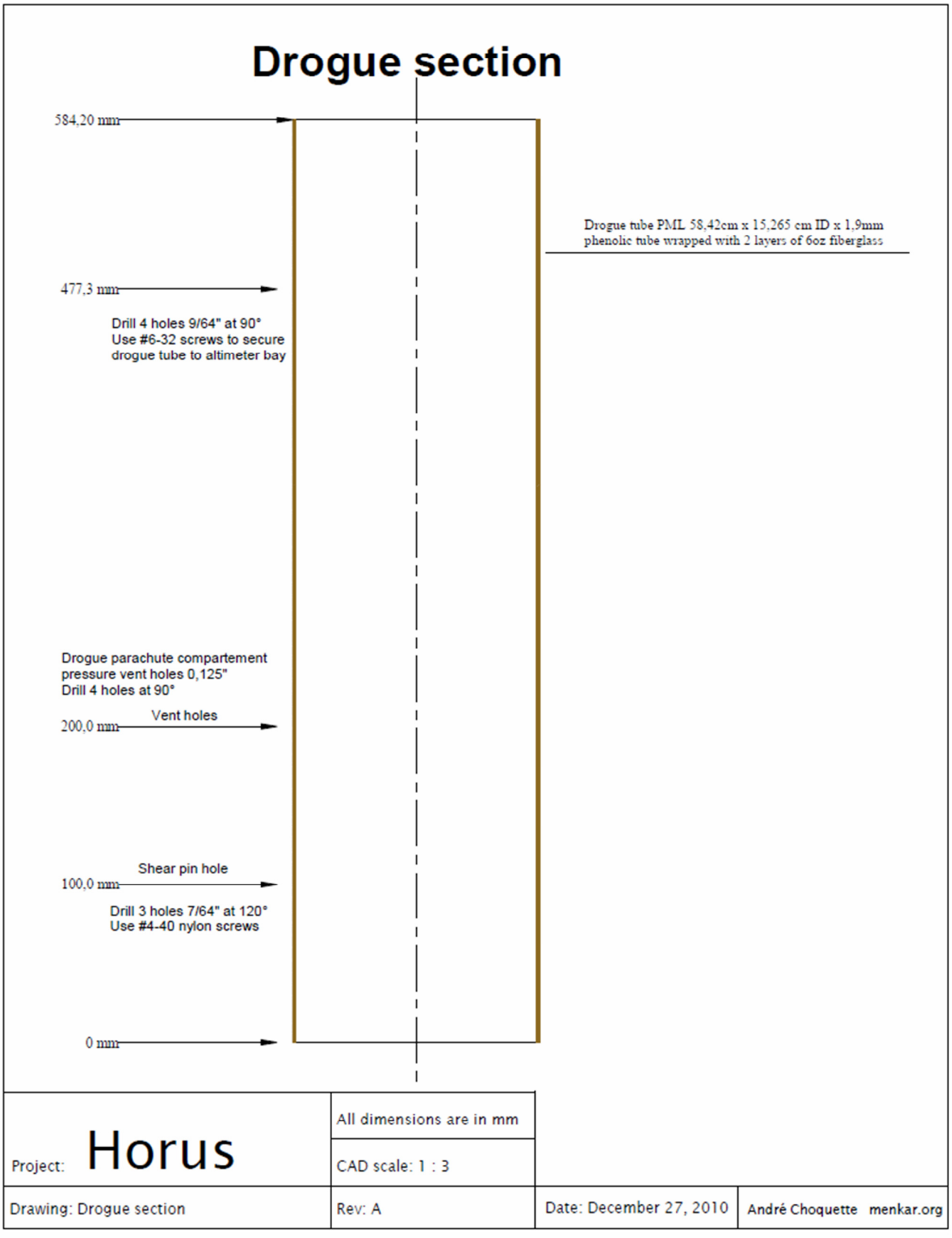
## Drawing 4 – Nose cone



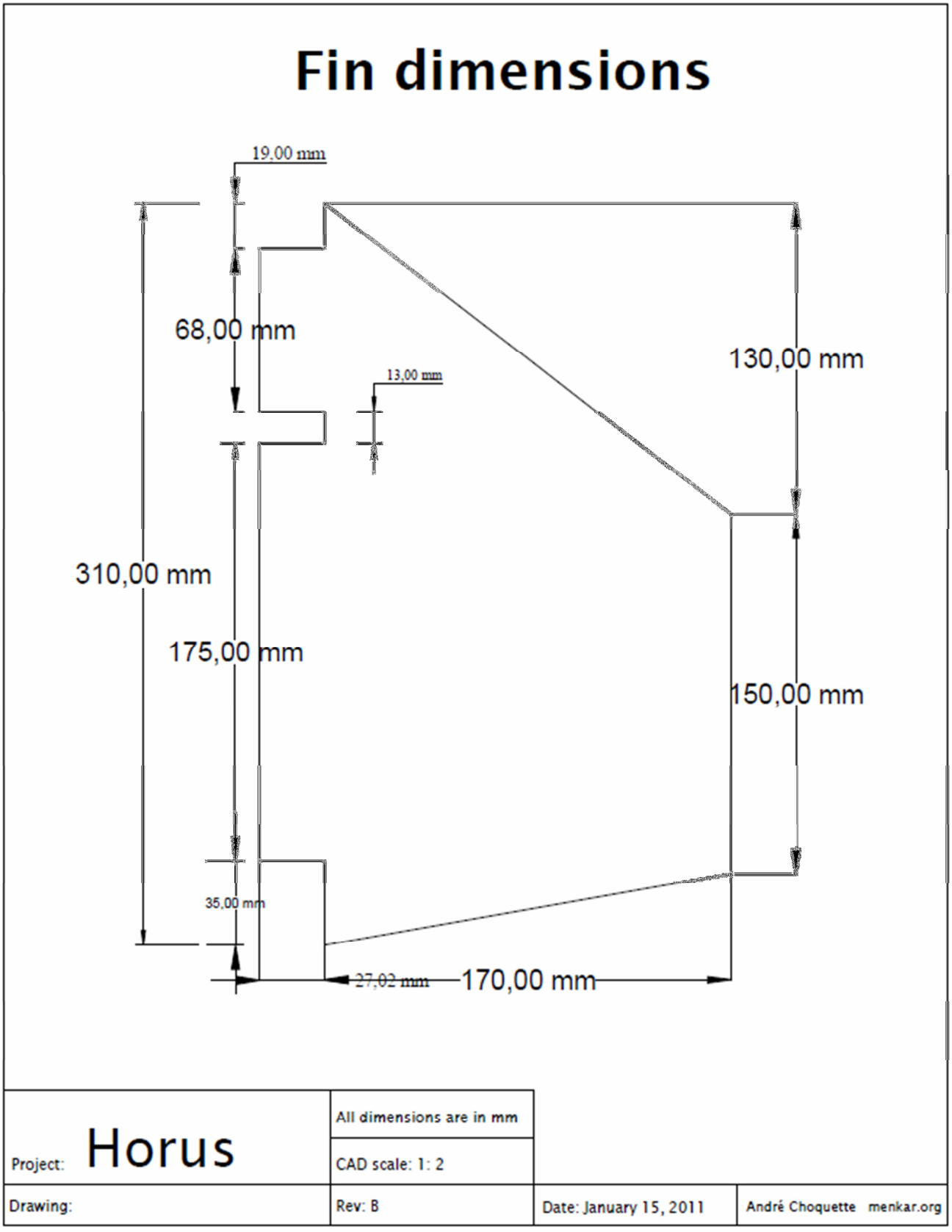
## Drawing 5 – Main section



## Drawing 6 – Drogue section



## Drawing 7 – Fins



# Fins

## Fin flutter analysis

Fin flutter analysis is based on Trapezoidal fin shape:

Root chord: 31cm (12,2")
Span: 17cm (6,69")
Tip chord: 15cm (5,91")
Sweep length: 13cm (5,11")

I don't have specialized software to calculate fin flutter. I used a special spreadsheet to evaluate the flutter velocity. The spreadsheet is based on NACA Technical Note 4197 which presents a simplified method for calculating fin flutter velocity based on the method of Theoderson. NACA TN-4197 has confirming data up to "at least Mach 1.3", so this analysis may not hold up for higher Mach numbers. NACA TN-4197 covers three different types of flutter: pitch-bending flutter, stall flutter, and torsion-bending flutter. The flutter that we experience in amateur rocketry is torsion-bending flutter, that is, flutter due to the fins twisting and bending because they are not stiff enough.

$$V_f = \frac{(V_a)(G_e)}{\left(\frac{p}{p_0}\right)\left(\frac{\lambda+1}{2}\right)\left(\frac{39.3(A^3)}{\left(\frac{t}{c}\right)^3(A+2)}\right)}$$

| | Description | Value |
|---|---|---|
| **Va** | Speed of sound | 766,22 mph |
| **Ge** | Shear modulus | 7,69Gpa (G10) - 53,85Gpa (CF) – 30,00Gpa (FG) |
| **A** | Aspect ratio | 0,92 computed with the spreadsheet |
| **P / P0** | Air pressure / Air pressure at sea level | Estimated at 1 (launch site are closed to sea level in Quebec) |
| **T** | Fin thickness | 0,125" (G10) and 0,150" (G10 + 2 layers of CF) |
| **C** | Root chord | 12,2" |
| **λ** | Tapper ratio (tip chord / root chord) | 5,91" / 12,2" = 0.4844 |

For 0,125" plain G10 the Shred velocity (2.2x flutter velocity) will be 2.2 x 304 = **668,8 mph**. Considering that the fins will be covered tip to tip with carbon fibre giving a new thickness of 0,150" and an adjusted Shear modulus of (6,152 + 10,77) = 16,922.

For 0.150" G10 and 2 layers of CF the Shred velocity will be 2.2 x 594 = **1306 mph or 583 m/s**. This value is well over the speed of any "M" impulse motor. For my L4 certification, the motor I choose will bring the rocket to a maximum speed of 282m/s. This is giving me a margin of more than 100%.

Now, for 6 layers of CF, 3 on each side, the thickness reach 0.166". The combined G10 and CF have a Shear Modulus of (.75 * 7.69 + .25 * 53.58) 19.09 this is giving the fin a Shred velocity of 2.2 x 734 = 1468 **mph or 656 m/s**. Even if this value is a bit optimistic, it is way over the 282m/s estimated for the certification flight. The biggest motor that can be used in Horus is the CTI 3400WT 4 grains and the maximum velocity is 420 m/s (Mach 1.26), well under the calculated shred velocity.

# Recovery System

## Electronics

In the main electronic bay two altimeters:

1- Missile Works RRC2 mini, drogue at the apogee and main at 1000'
2- Featherweight Altimeters Raven, drogue at apogee +1 sec and main at 900'

Each altimeter has its own apogee and main black powder canister, for a total of 4 canisters and e-matches.

The RRC2 is used in the 2X 9V battery configuration, one for the altimeter itself and the second one for the charges.

The Raven is used with 1X 9V battery, the Raven do include an aerogel ultra-capacitor to keep the altimeter alive in case of temporary disconnection (10 to 20 sec.).

A Beeline GPS is located in the nose cone (70cm band).
Frequency: 429,750 MHz

## Parachute

- Drogue, Cert 3 – Drogue by SkyAngle
- Main, Cert 3 – Xlarge parachute by SkyAngle

Descent rate under the Drogue: 14,3 m/s (51 km/h) - 46,9 ft./s (31.9 mi/h) (Rocksim)

Descent rate under the Main parachute: 4,3 m/s (15,4 km/h) - 14 ft./s (9,6 mi/h) (Rocksim)

Shock cords are protected with Kevlar sleeves on the first 30", the parachute and the other 35' of shock cords are protected by Nomex blankets.

Given the size of the main parachute, predicted deceleration forces are predicted to be significant. Thus techniques such as configuring the cord to dissipate energy and the utilization of stretch cords will be utilized to minimize the deployment forces for the main parachute.

## Ejection charge calculation

The ejection charge for the project will be FFFG black powder (the only available and work like the 4F). The pressure I want to reach is about 15 psi. For 15 Psi, we can use the formula:

F = PA, F=Force, P=Pressure, A=Area ➔ P = 15 * pi * (D/2)2 ➔ P = 424

N = 0.00052 * FL F= 424, L = length of tube to pressurize

Drogue: N= 0.00052 * 424 * 11.77" = 2,5g
Main: N= 0.00052 * 424 * 30.9" = 6.8g rounded to 7,0g

Those numbers have to be confirmed with ground static tests. Those tests will be used to check that the ejection charge can separate and eject the parachute with the 3x #4-40 nylon shear pins.

## Drag separation

### Nose code

Drag separation can occur immediately after main motor burn out due to the differential acceleration between the different components of the airframe. Let's assume there is no friction between the nose cone and the airframe. The maximum force applied on the nose cone will be:

Nose cone weight: 1,1kg (including bulkheads, U-bolt and electronic tube)
Harness and parachute: 2kg
Total: 3,1kg

Maximum deceleration (Calculated with Rocksim) at 4,9 sec. : -2,294 = 2,294 * 9,81m/$s^2$ = 22,5m/$s^2$

F = M * A = 3,1 * 22,5 = 69,8 N ➔ 15,69 lbf

### Upper section

Nose cone weight: 1,1kg (including bulkheads, U-bolt and electronic tube)
Harness and parachute: 2kg
Electronic bay:
Drogue section (including harness and drogue):
Total: 13,3kg

Maximum deceleration (Calculated with Rocksim) at 4,9 sec. : -2,294 = 2,294 * 9,81m/$s^2$ = 22,5m/$s^2$

F = M * A = 13,3 * 22,5 = 299,3 N ➔ 67,3 lbf

## Shear pins sizing

#4-40 Nylon 6/6 screws have a shear Strength of 9600 to 10500 psi.

With a diameter (smaller) of 0,08130" or a section area of 0,0051912 sq. inch, a nylon screw has at minimum a shear strength of 0,0051912 * 9600 = 49,8 lbf.

Three of them will have 149,4 lbf of strength, 10 times more than the maximum deceleration produced by at the burnout of the main motor for the nose cone and main section and more than 2 times for the upper rocket sections (drogue, electronic bay, main and nose cone).

#2-56 Nylon 6/6 screws have a shear Strength of 9600 to 10500 psi.

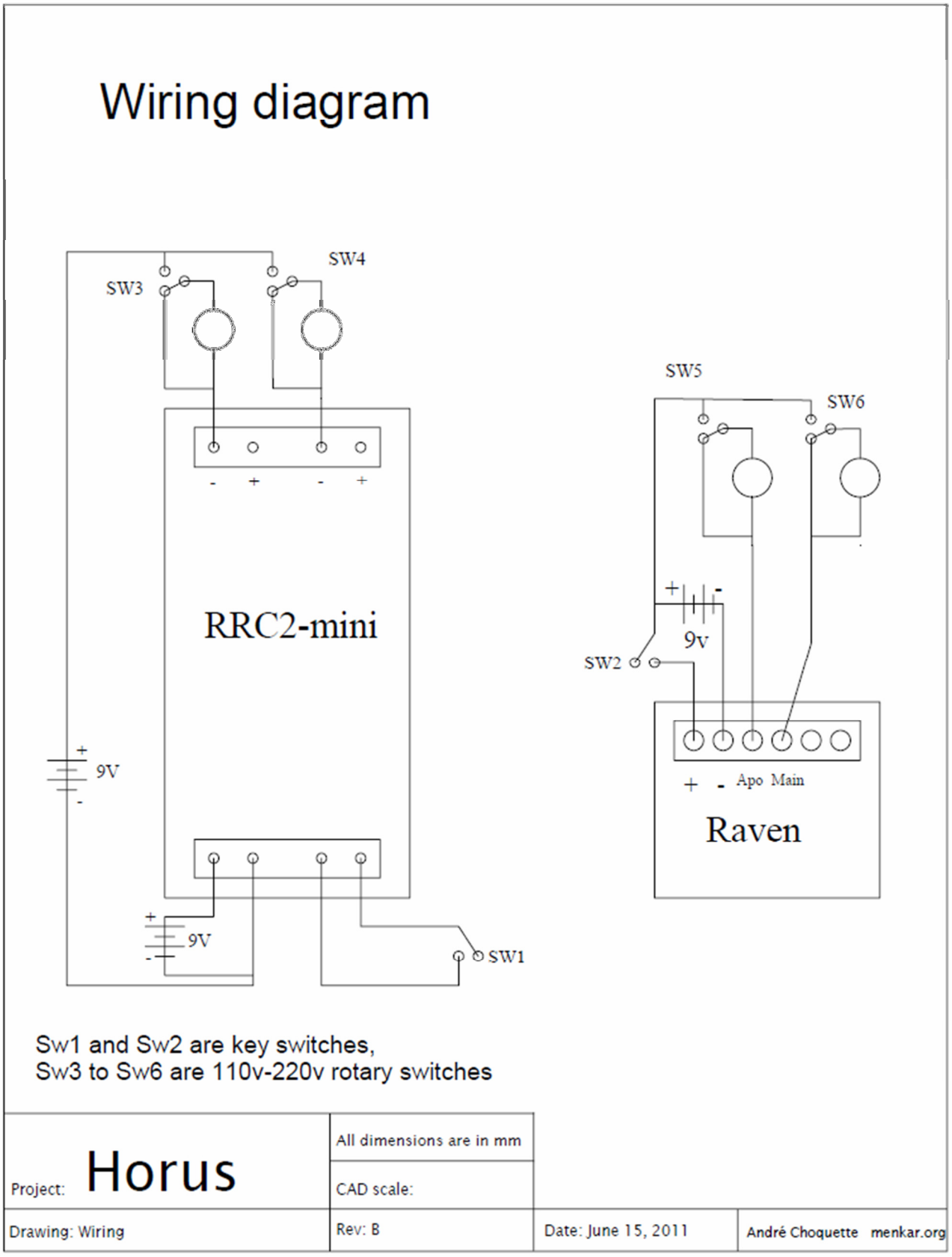
With a diameter (smaller) of 0,06410" or a section area of 0,0032271 sq. inch, a nylon screw has at minimum a shear strength of 0,0032271 * 9600 = 30,9 lbf.

Three of them will have 92,9 lbf of strength, almost 7 times more than the maximum deceleration produced by at the burnout of the main motor  and more than 1,5 times for the upper rocket sections (drogue, electronic bay, main and nose cone).

Using 3x #4-40 Nylon 6/6 screws will give a better margin of safety against premature ejection of the main parachute.  The ejection charges will produce more than 400lbf more than enough to shear the 3 #4-40 screws.

Ground tests will be run to confirm those numbers.

## Wiring diagram



## Performance

Weight empty:  16,6 Kg  - 36,6 lbs.
Weight loaded:  23,3 Kg -  51,4 lbs.
Motor:  CTI 7579 M1520 BS
Burn time: 4,9 sec.
Thrust to weight ratio: 6,65

Maximum altitude:  3450m  -  11300 ft.
Maximum Gees:  9,55
Maximum speed:  282 m/s  (1015 km/h)  - 925 ft./s  (630 mi/h)
Time to apogee:  26,5s
Speed at launch guide departure (3m) :  19,1 m/s (69 km/h)  -  63 ft./s  (43 mi/h)
CG from the nose cone:  203,1cm
CP from the nose cone:  227,9cm
Static margin: 1,60

Flight simulation by:  Rocksim 9.0

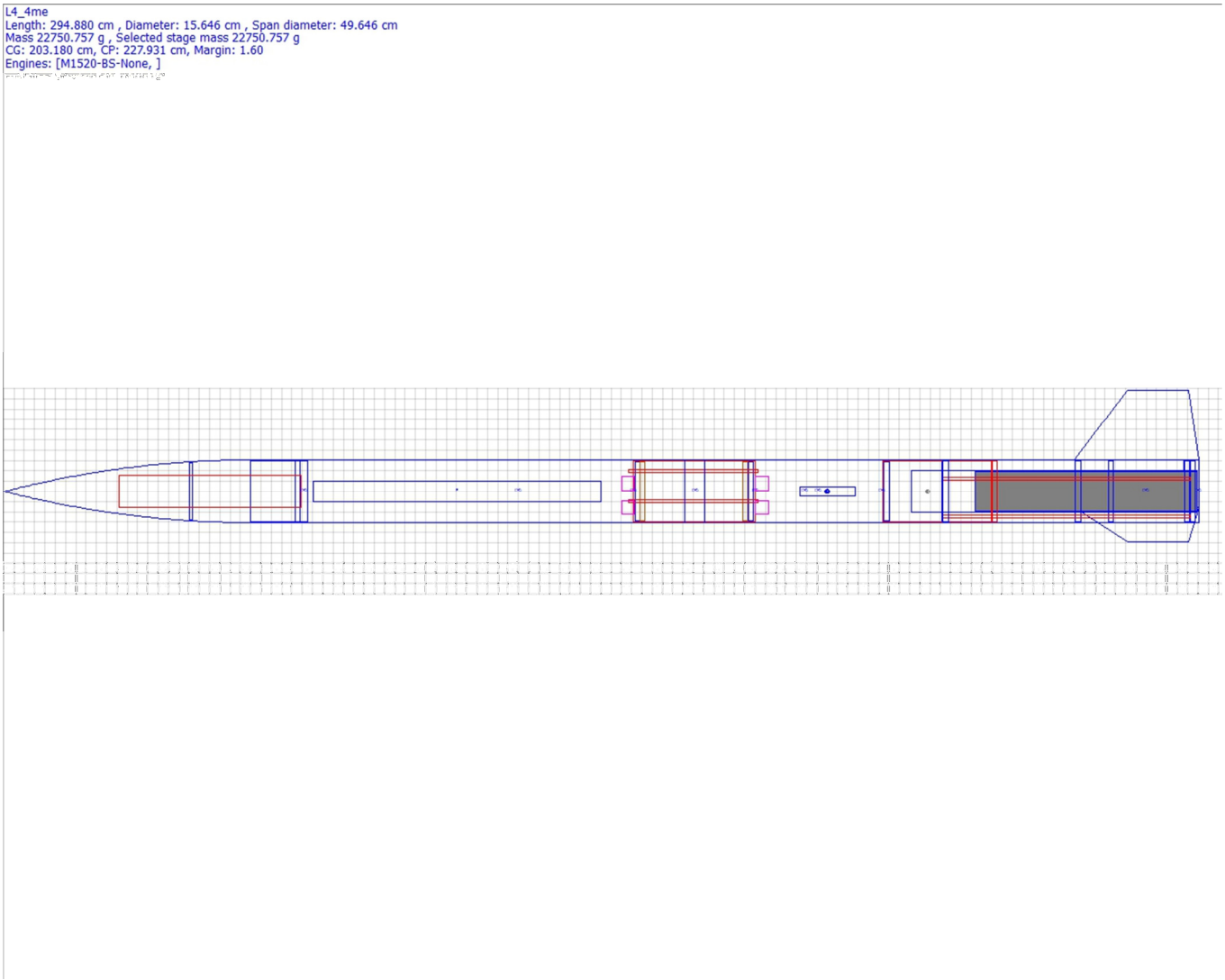
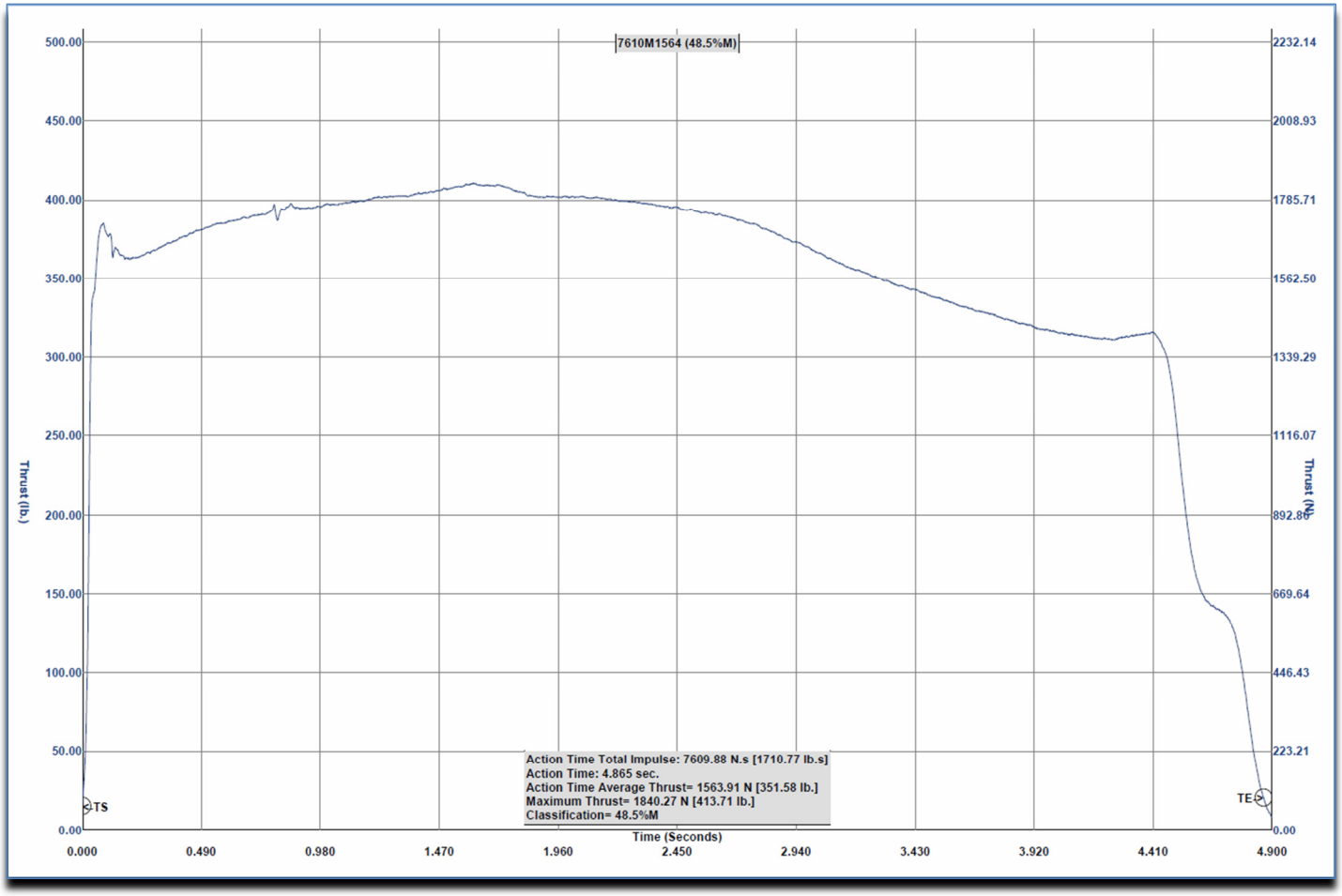


Figure 1. Motor thrust curve



# Pre-launch Checklist

## Assembly checklist

### Ejection system

- [ ] 1- Verify if the Raven is correctly program
    - a. Drogue - Apogee + 1 second
    - b. Main – 900'
- [ ] 2- Verify if the RRC2-mini is correctly program
    - a. Drogue - Apogee
    - b. Main – 1000'
- [ ] 3- Put all master arming switches OFF (1x main and 1x drogue charges)
- [ ] 4- Make sure both power switches are OFF
- [ ] 5- Install fresh batteries in all electronics, total 3 (2x RRC2 and 1x Raven), should read > 9,5v
- [ ] 6- Verify all wires to the altimeters
- [ ] 7- Install the electronic sled in the bay
- [ ] 8- Seal the altimeter bay
- [ ] 9- Install an electronic match in each Drogue canister, secure with tape
- [ ] 10- Install an electronic match in each Main canister, secure with tape
- [ ] 11- Turn ON all switches
- [ ] 12- Confirm the continuity, RRC2 should emit 3 short beeps and the Raven should emit 2 beeps (one per charge)
- [ ] 13- Turn OFF all switches
- [ ] 14- Main chute Canister - Place 7g of black powder per canister, secure with wadding and tape
- [ ] 15- Drogue chute Canister - Place 2,5g of black powder per canister, secure with wadding and tape

### Recovery system

- [ ] 1- Connect the Drogue shock cord with Nomex to the electronic bay
- [ ] 2- Install Drogue section tube to the electronic bay and tighten the 4 screws
- [ ] 3- Connect the Drogue shock cord to the booster section
- [ ] 4- Pack shock cord and drogue chute in the lower body section with Nomex blanket
- [ ] 5- Install the 2 shear pin
- [ ] 6- Connect the Main shock cord with Nomex to the electronic bay
- [ ] 7- Install Main section tube to the electronic bay and tighten the 4 screws
- [ ] 8- Connect the Main shock cord to the nose cone
- [ ] 9- Pack shock cord and the main chute in the upper body section with Nomex blanket

### GPS recovery system

- [ ] 1- Turn ON the Beeline GPS
- [ ] 2- Turn ON the receiver on 429,750 MHz on the second VFO
- [ ] 3- Verify the reception of the APRS packet
- [ ] 4- Install the sled in the nose cone
- [ ] 5- Secure with 3x #6-32 screws
- [ ] 6- Install the nose cone and secure it with the 3 shear pin

## Motor assembly

- [ ] 1- Assemble Motor hardware and re-load per CTI instructions
- [ ] 2- Slip motor assembly into the motor tube
- [ ] 3- Screw the Aero-pack retainer tightly over aft end motor
- [ ] 4- Confirm the center of gravity
- [ ] 5- Tape the igniter and screw driver to the motor tube

## Final assembly check

- [ ] 1- All #6-32 screws holding airframes to electronic bay are tight
- [ ] 2- All #4-40 shear pins are in place
- [ ] 3- Motor retainer is tight
- [ ] 4- All static port and vent hole are clear of debris
- [ ] 5- Fill out launch card at RCO table

## Pre-flight checklist

### Launch check

- [ ] 1- Turn the power switch ON for the RRC2, it should emit a single long beep (no charge detected)
- [ ] 2- Turn the power switch ON for the Raven, it should emit a single low beep (no charge detected)
- [ ] 3- Turn ON the charges switch for the RRC2
- [ ] 4- RRC2 - Confirm the continuity, should have 3 short beeps
    - **a. If readings are not ok: turn OFF all electronics and shunt all the charges**
- [ ] 5- Turn ON the charge switch for the Raven
- [ ] 6- Raven - Confirm the continuity, should have 2 high pitch beep (one per charge)
    - a. **If readings are not ok: turn OFF all electronics and shunt all the charges**
- [ ] 7- Install the igniter in the motor
- [ ] 8- Connect the launch system leads to the motor igniter
- [ ] 9- Check for continuity at launch battery supply

### Pad failure

- [ ] 1- Wait for the authorization of the LCO or RSO before going to the launch pad
- [ ] 2- Disconnect the igniter
- [ ] 3- Remove the igniter
- [ ] **4- Turn OFF all the electronics and shunt the charges**

## Post-flight checklist

- [ ] 1- Bring help to carry the rocket back
- [ ] 2- Bring radios, APRS receiver
- [ ] 3- Secure landing site
- [ ] **4- Turn OFF all the electronics and shunt the charges**
- [ ] 5- Bring back the sections
- [ ] 6- Bring the rocket to the L4CC for inspection