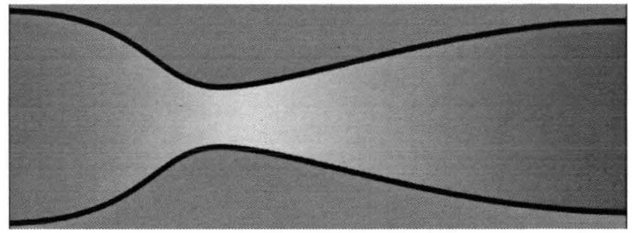
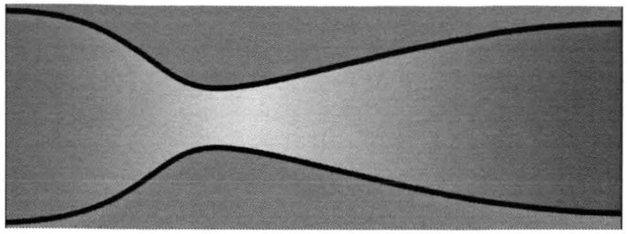


Hybrid Rocket Experiment Station for Capstone Design

Thursday and Friday, July 19&20, 2012
Kennedy Space Center



Edgar Conley, Assoc. Professor
Jacob Valencia, Research Asst.

Mechanical and Aerospace Engineering Department

New Mexico State University

Las Cruces, NM 88011

Agenda

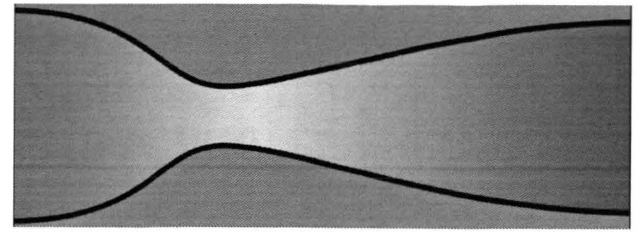
Thursday

Topic	Time
KSC Tour and Lunch	8:30 – 12:45
Welcome and Introductions	1:00 – 2:00
NASA Systems Engineering Overview	2:00 - 3:15
Break	3:15 – 3:30
NASA Systems Engineering Overview Continued	3:30 - 4:30
Open Discussion - All	4:30 – 5:00
Optional Dinner (faculty's expense) - Fishlips Waterfront Bar & Grill, Port Canaveral	6:00 pm

Friday

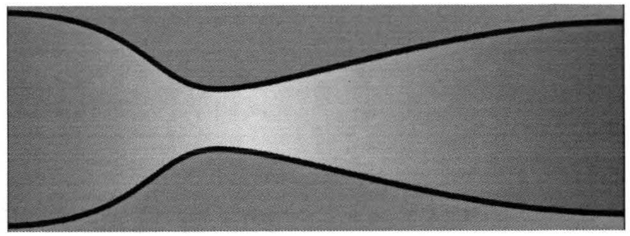
Topic	Time
Welcome	8:00 – 8:10
Generic Capstone Design Overview – Edgar Conley	8:10 – 9:00
Open Discussion - All	9:00 - 10:00
Break	10:00 - 10:15
Hybrid Rocket Experiment Station for Capstone Design, Part 1 Implementation – Edgar Conley	10:15- 11:30
Lunch	11:30 – 12:30
Hybrid Rocket Demonstration – Jacob Valencia	12:30 – 2:30
Break	2:30– 2:45
Hybrid Rocket Experiment Station for Capstone Design, Part 2 Continued Use – Edgar Conley	2:45 – 4:15
Open Discussion - All	4:15– 5:00

Part 1 - Implementation



- Capstone Design Overview at NMSU
- Hybrid Rocket Experiment Station – starting from zero

Capstone Design Overview ME426/ME427/AE428



NMSU course extends over one or two semesters – one full academic year for MEs; one semester for AE students.

Four to six students per team depending on project scope; usually multidisciplinary.

Class has instructor of record. Each team also generally has a faculty mentor in addition to a 'client.'

Projects are organized with local industry, service organizations, and government laboratories.

Projects sometimes supported by sponsor with funding; sometimes not.

Students meet weekly with faculty of record and with faculty mentor, as required.

Generally, problems are practical and 'real-world.'

Projects usually culminate with a working design.

Lecture topics:

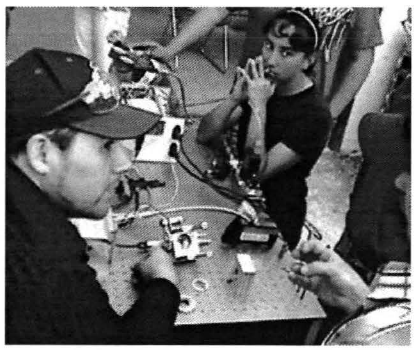
- Four to five class periods reviewing the generic design process at semester onset.
- Remaining class time is used for project work, meetings, and presentations.

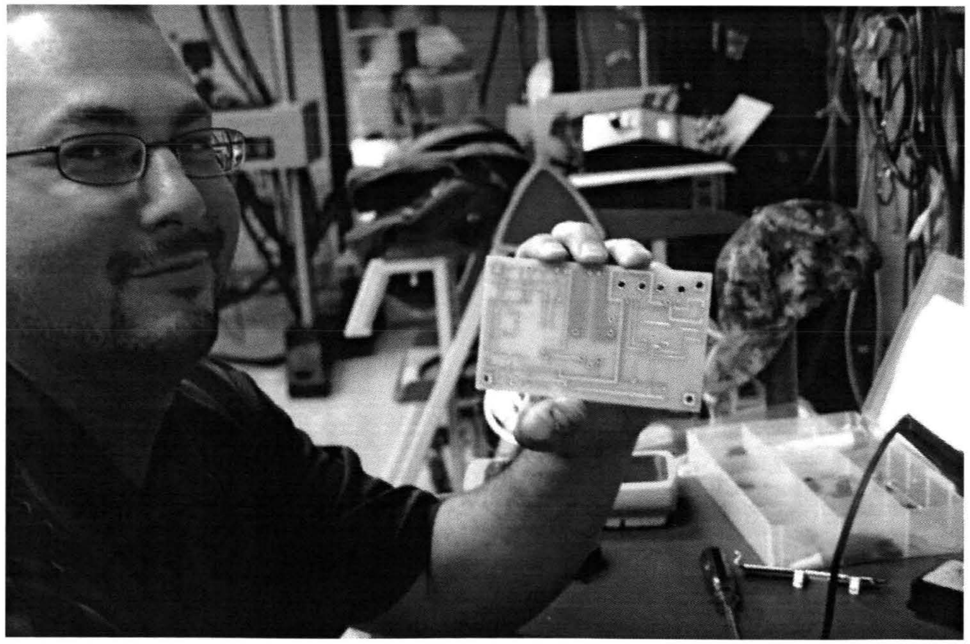
Assessments based on:

- Reports and Presentations.
- Proposal; Progress (systems analysis & conceptual design); Final (final design & evaluation).
- Weekly progress reports.
- One or two pages on activity journal for team.
- Peer, faculty, and client evaluations.

Multidisciplinary Teams

Several disciplines are often represented:
English (tech writer)
Business (accounting, project management)
Industrial, Electrical, Mechanical and Aerospace Engineering





NASA Systems Engineering Handbook

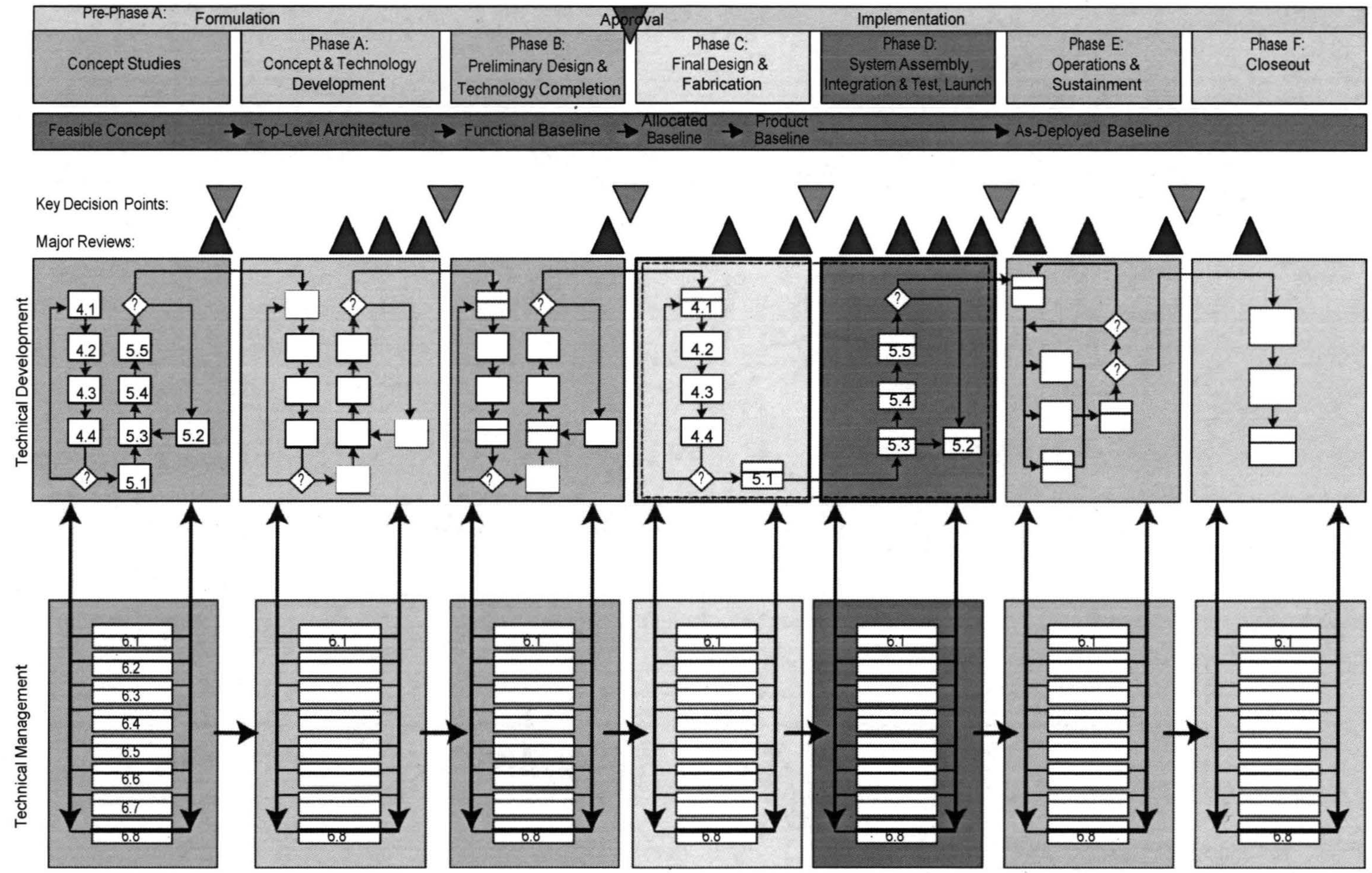


Figure 2.2-1 A miniaturized conceptualization of the poster-size NASA project life-cycle process flow for flight and ground systems accompanying this handbook

EXAMPLE STUDENT REPORT

New Mexico State University

Hydra-Chew

The Ultimate Assistive Technology Breakthrough

Prepared for: Dr. Y.H. Park, Professor ME426

Fall 2010

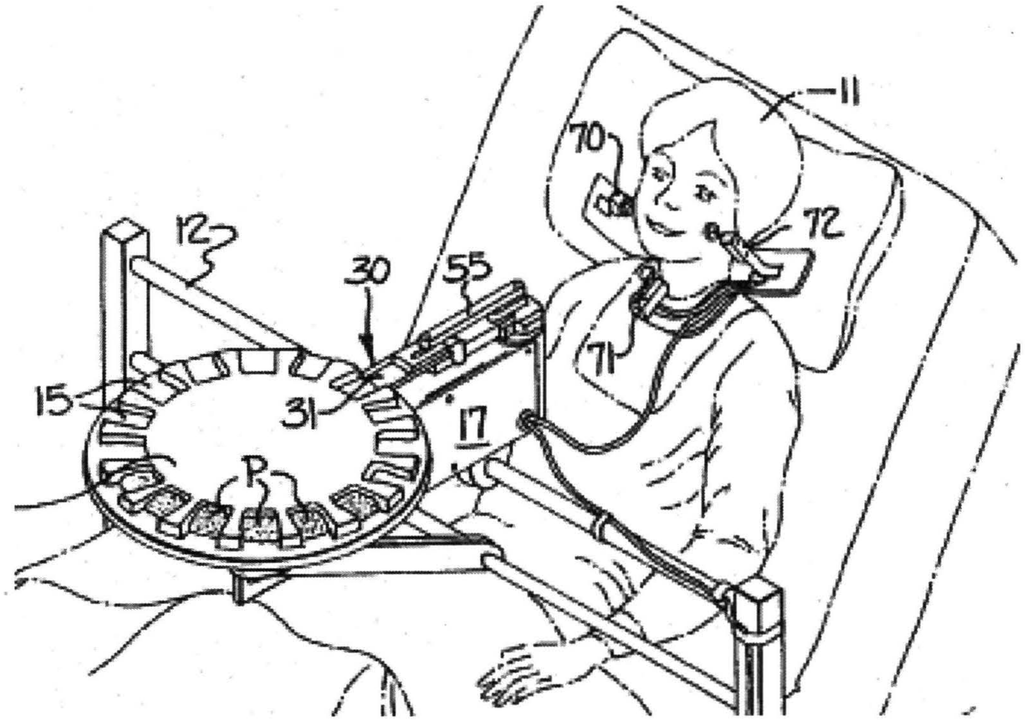
NMSU Structured Design Process

Facet 1 – Recognize and Quantify the Need
Facet 2 – Problem Definition
Facet 3 – Concept Development
facet 4 – Feasibility Study *
Facet 5 – Preliminary Design *
Facet 6 – Engineering Modeling and Analysis
Facet 7 – Detailed Design
Appendix A – Analysis
Appendix B – Progress Reports
Appendix C – Scheduling and Milestones
Appendix D – Miscellaneous

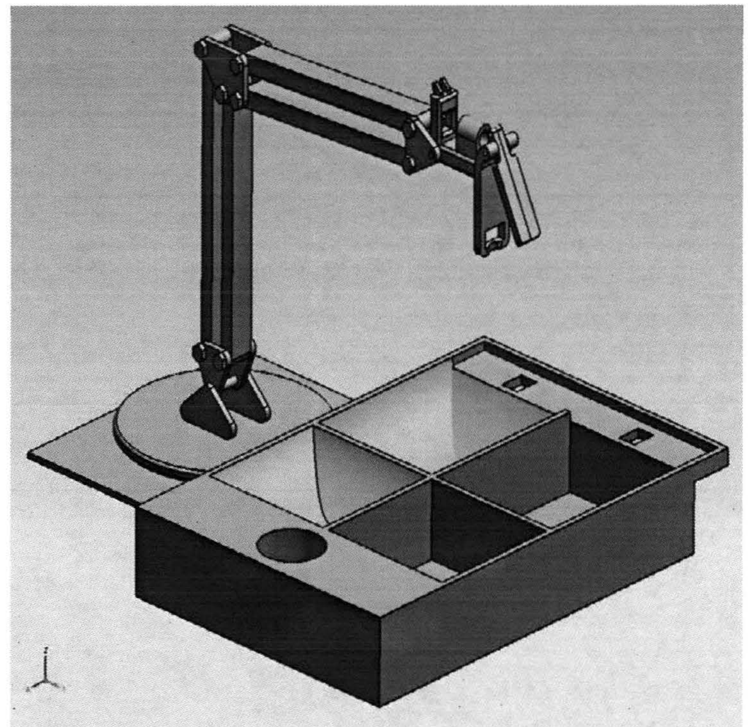
Typical Feasibility Assessment Questions

Project: Self feeding device
Technical Question: Does the team have the skills needed to implement all aspects of the technologies for the concept?
Technical Question: Does the team have the resources for the concept?
Performance Question: Is the concept durable?
Performance Question: Can the concept achieve speed and agility?
Economic Question: Can the team members cover the cost of construction?
Schedule Question: Can the concept be built by the time of the competition?
Marketing Question: Is the concept reusable?
Feasibility Question: What is the state of the art?
Feasibility Question: Do we have time to complete the project?

EXAMPLE STUDENT REPORT



State of the art –
results of patent search



preliminary
design

Capstone Design Open Discussion

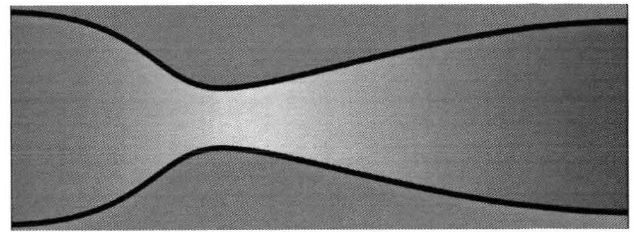
Break out groups (one hour)

In groups of 3-4, consider the following issues, and be ready to summarize your comments as a group.

- Team selection.
- Source of your senior design project topics.
- Make-up of your senior design teams: Single discipline, multi-discipline, etc.
- Supervision: Who supervises (1 faculty, team of faculty, etc.), 1 or 2 semester.
- Things you've tried in your senior design projects that have worked well.
- Things you've tried in your senior design projects that have not worked well.
- Your use of peer evaluation.
- Persistent problems.

Break (15 minutes)

Group Discussion (40-50 minutes)

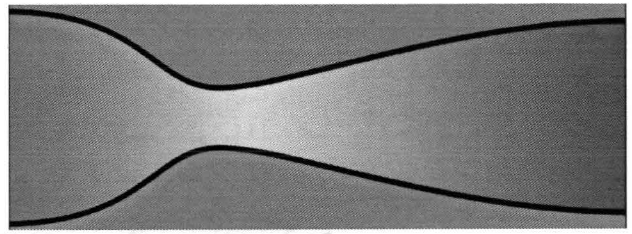


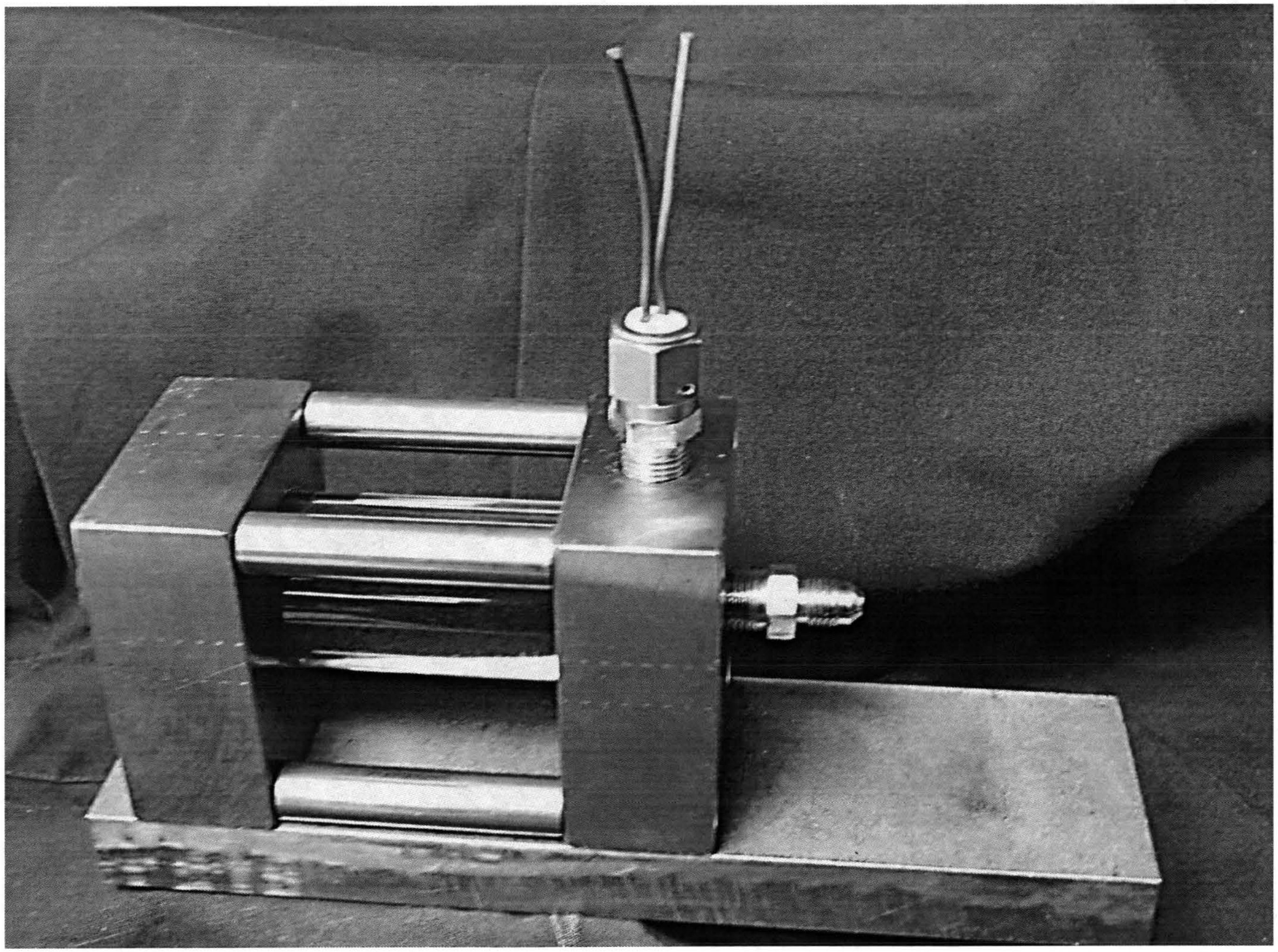
Part 1 - Hybrid Rocket Experiment Station Implementation

hybrid rocket test

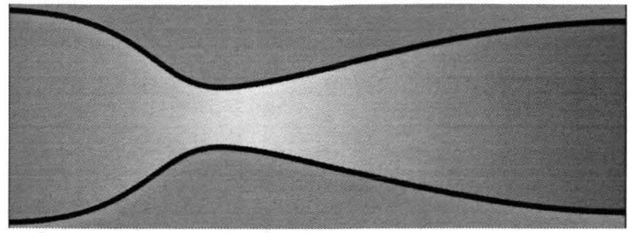
video

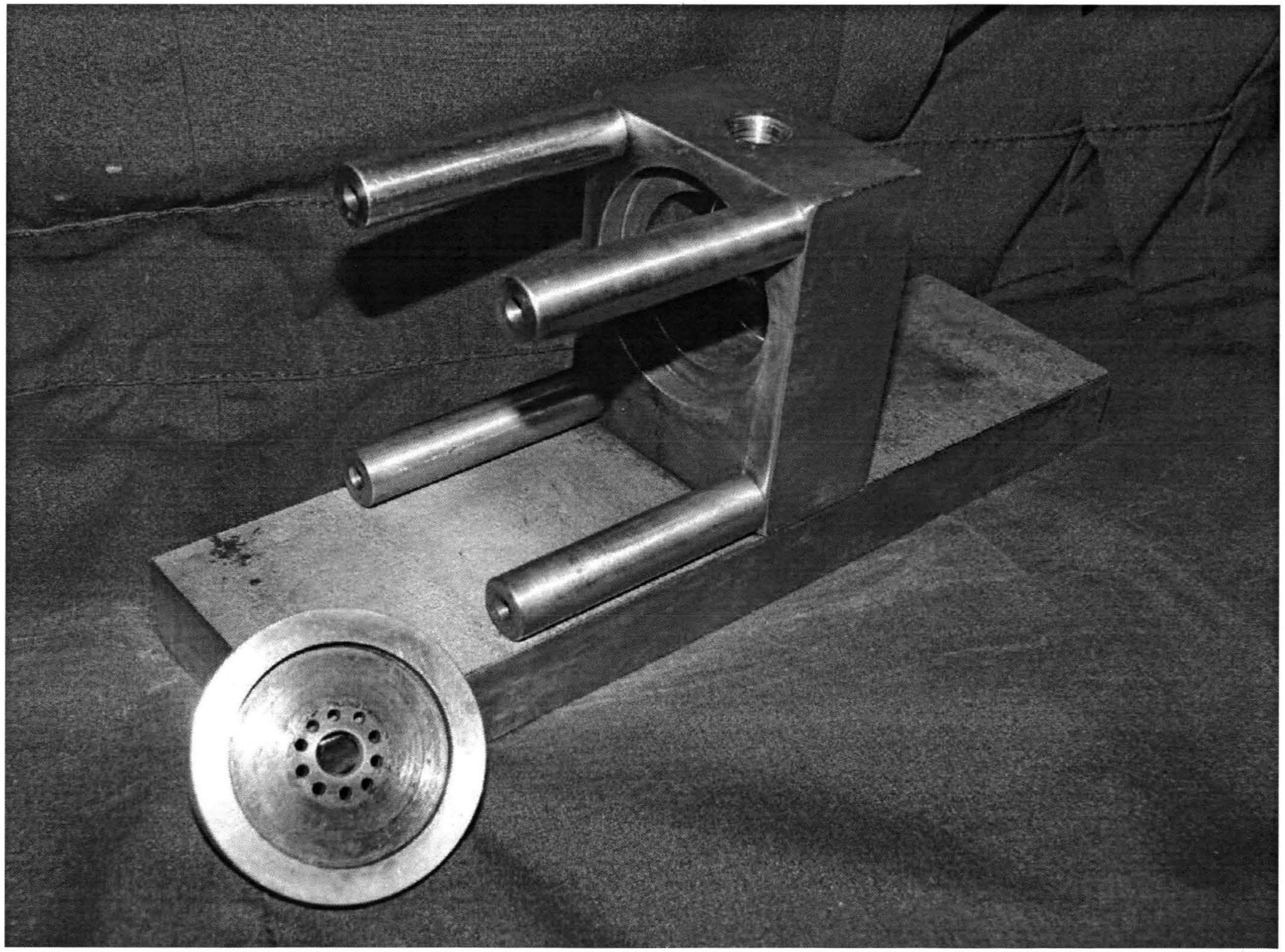
NASA Classroom Propulsion Demonstrator



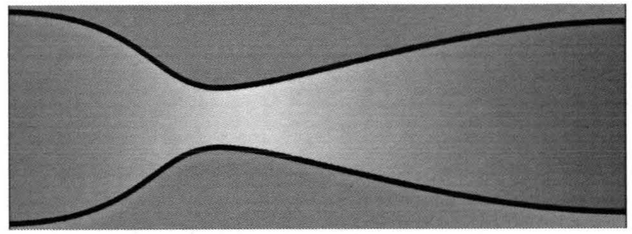


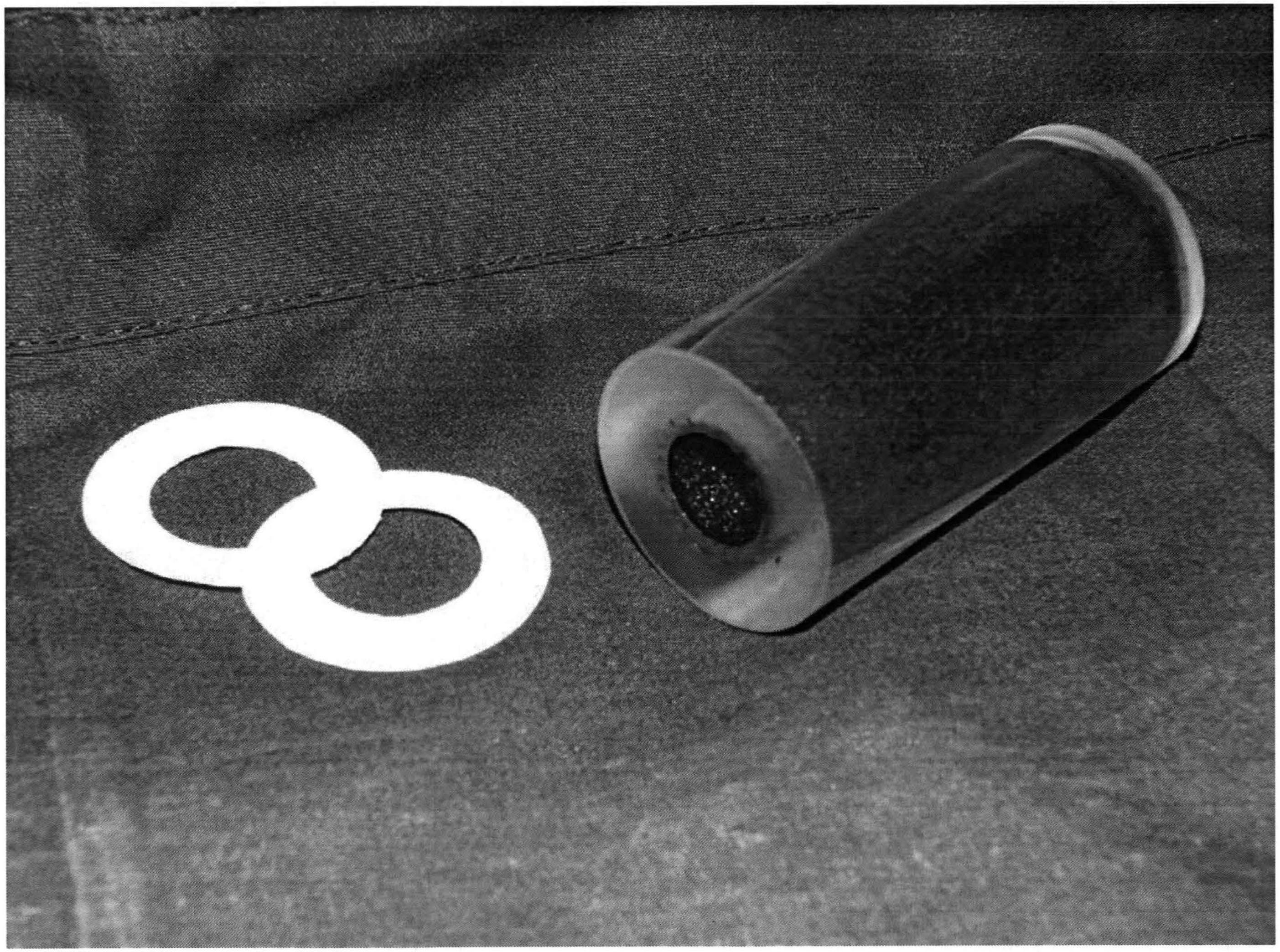
NASA Classroom Propulsion Demonstrator



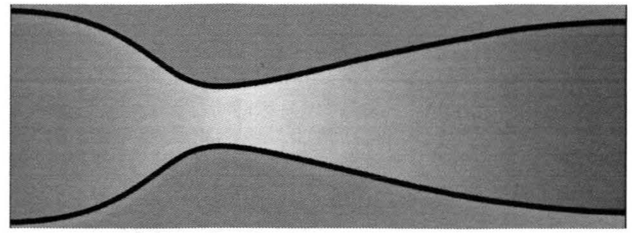


NASA Classroom Propulsion Demonstrator

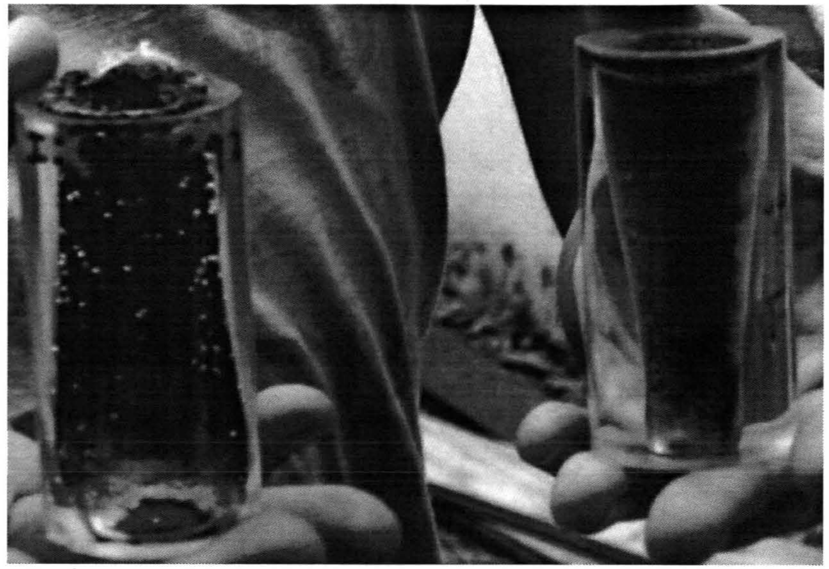


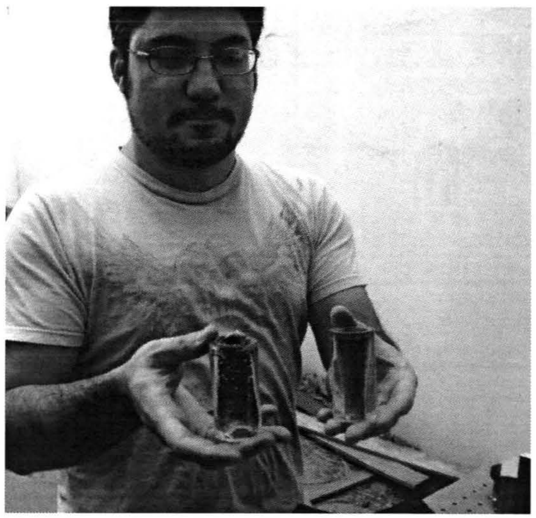


NASA Classroom Propulsion Demonstrator



Extruded acrylic (PMMA), the preferred fuel, appears in left hand; cast acrylic appears in right hand.



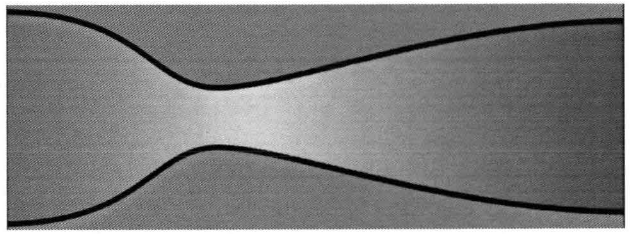


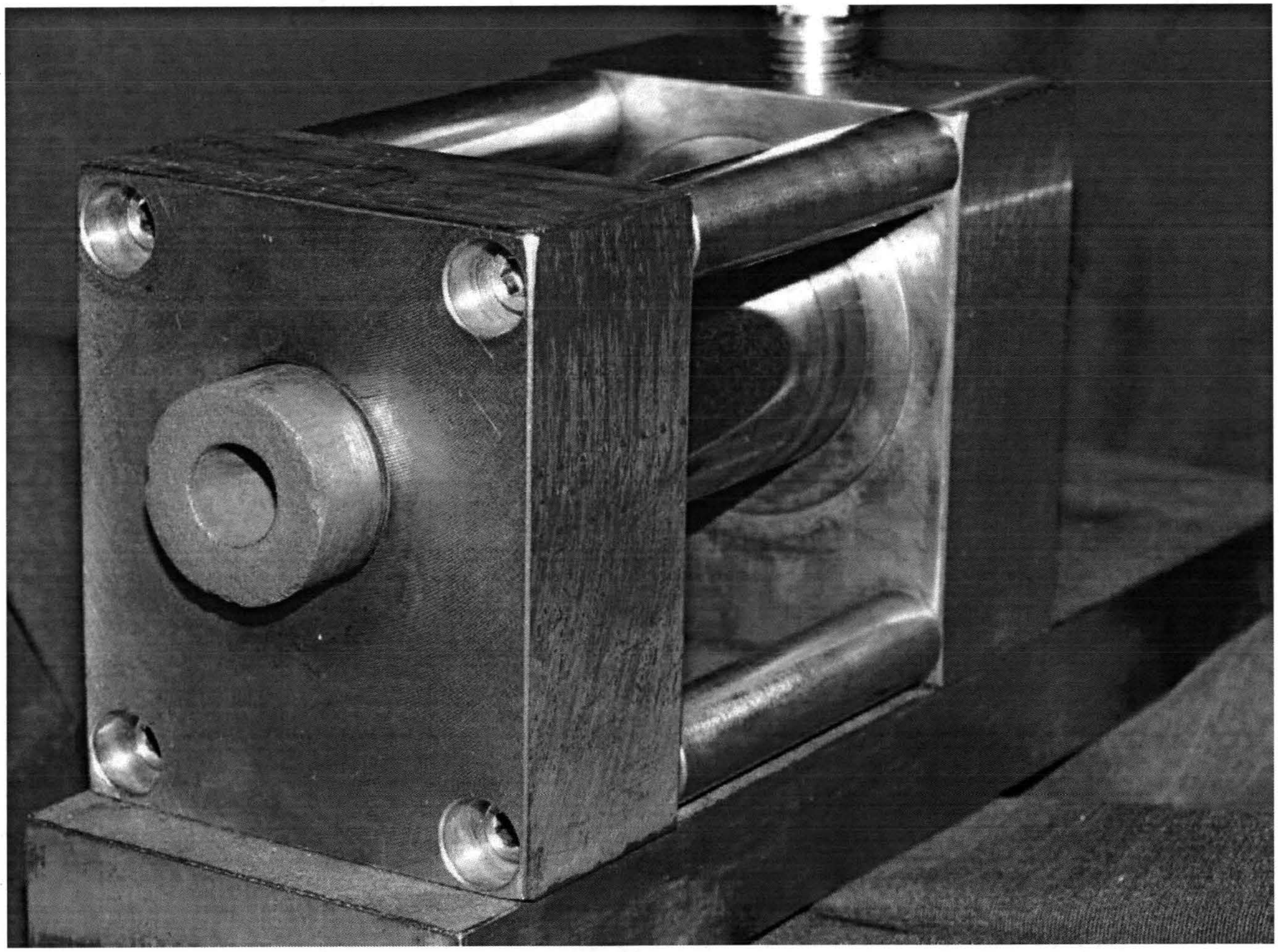
$C_5H_8O_2 + 6\ O_2 \rightarrow 5\ CO_2 + 4\ H_2O$

E = 13.1 kJ of heat released per gram of diatomic oxygen (O_2) consumed.

HEATS OF COMBUSTION OF HIGH TEMPERATURE POLYMERS
Richard N. Walters*, Stacey M. Hackett* and Richard E. Lyon
Federal Aviation Administration William J. Hughes Technical Center
Fire Safety Section AAR-422
Atlantic City International Airport, New Jersey 08405
*Galaxy Scientific Corporation
2500 English Creek Avenue, Building C
Egg Harbor Township, New Jersey 08234

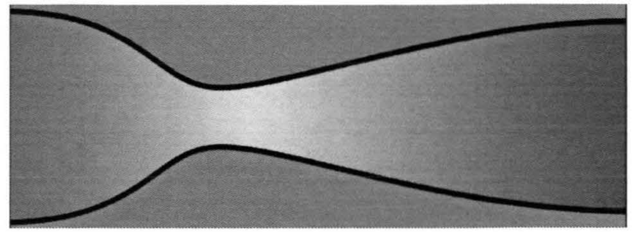
NASA Classroom Propulsion Demonstrator





Project Requirements

Phillip Hebert and Bryon Maynard
NASA Stennis Space Center



Classroom Propulsion Demonstrator (CPD)

1. CPD shall be easily portable. Able to transport from a car/truck to a classroom via one person; envision a suitcase size device.
2. CPD combustion products shall not be toxic, smelly, or produce little smoke/soot; fuel is to be ***extruded*** acrylic, "PMMA."
3. CPD shall be able to be set up in no more than 15 minutes.
4. CPD shall have the following instrumentation: thrust measurement, oxidizer flow rate, chamber pressure, gas oxygen temperature, nozzle exit temperature, battery voltage.
5. CPD shall be able to perform a preset thrust profile (oxidizer flow programmatically adjustable).
6. All CPD components shall be able to be repaired or replaced in the field.
7. All CPD instrumentation shall be able to be replaced with spare in the field.
8. All CPD instrumentation data will be displayed on a flat LCD screen.
9. CPD data from firings shall be saved and easily retrieved.
10. Activation and Control of CPD shall be automatic with provision for manual control.
11. The CPD shall have a reusable in-place ignition system.
12. CPD shall be able to fire continuously for a duration greater than 20 seconds.
13. CPD shall be able to do a minimum four test firings in one hour.
14. The CPD controls shall assess readiness for operation (e.g. electrical power; igniter continuity, oxidizer pressure, article temp for restart).
15. CPD shall be able to present a pre-recorded video data of actual rocket testing on its LCD screen.
16. CPD shall operate via graphic user interface.
17. CPD shall display propulsion graphically, showing discharge changing in respect to fuel and oxidizer changes.
18. CPD shall graphically show the relationship between all propulsion variables.
19. Both recorded data and video shall be time-stamped.
20. The post-test data shall be time-aligned to a start event.
21. CPD shall have an Emergency Shut-Off capability which will remove the oxygen supply from the device.
22. Data Display shall not interfere with data acquisition and recording operations.
23. CPD shall be capable of firing horizontally.
24. CPD design team shall provide end-to-end system uncertainty calculations in terms of percentage of full scale ranges.

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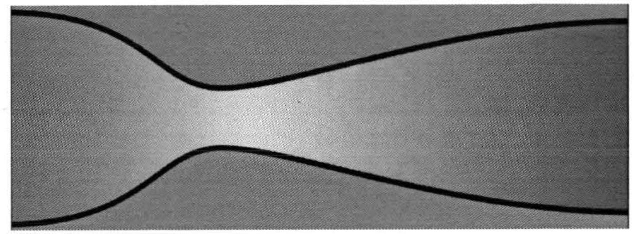

Sub-teams were organized based on deliverables

1. thrust measurement
2. temperature sensing
3. plumbing: O2 flow control, pressure sensing
4. data acquisition and control
5. reusable in-place ignition system
6. documentation: assembly and operator's manuals, safety
7. packaging for portability

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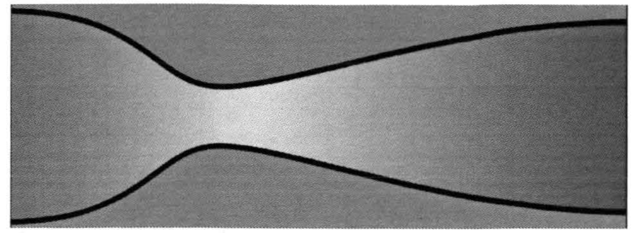
NASA

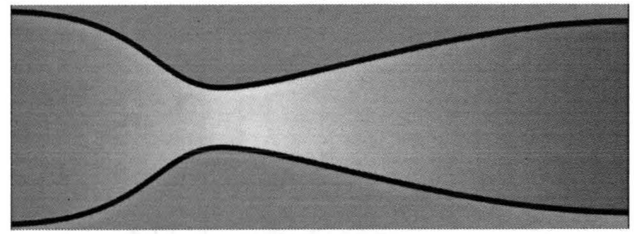
1. thrust measurement

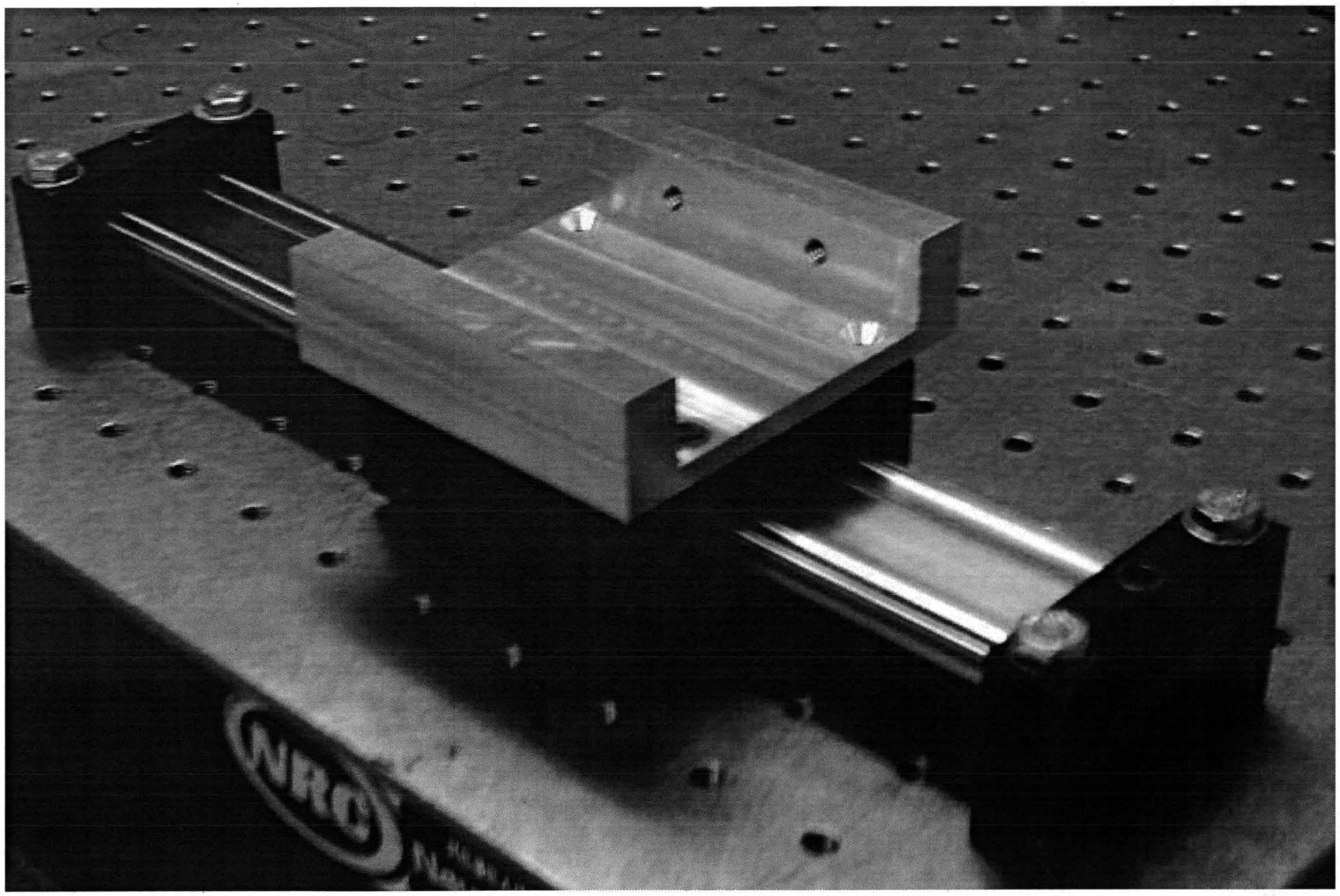
two alternative designs
are described



- Linear bearing slide w/load cell
- ‘Four bar’

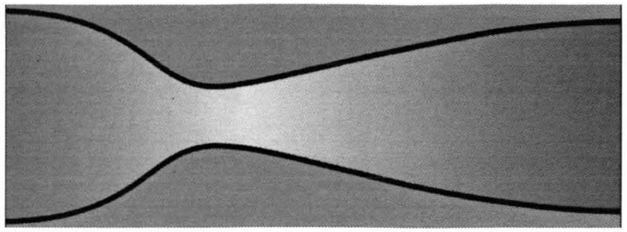
thrust measurement

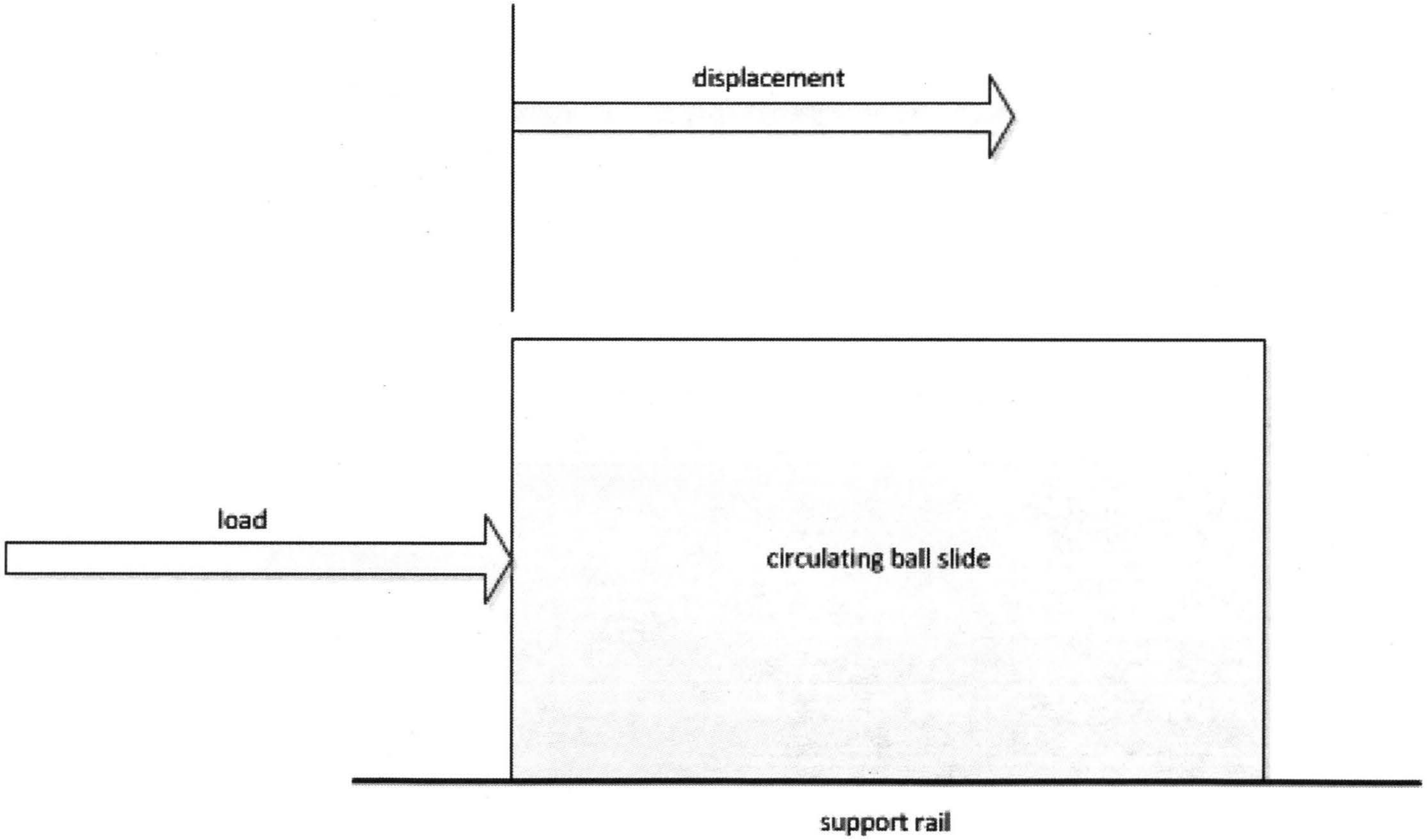




linear bearing slide

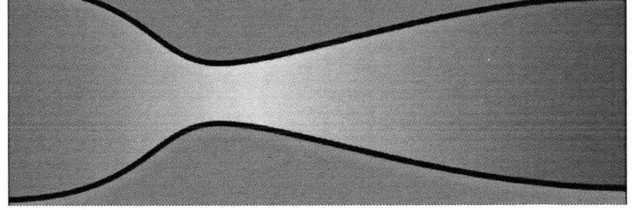
thrust measurement

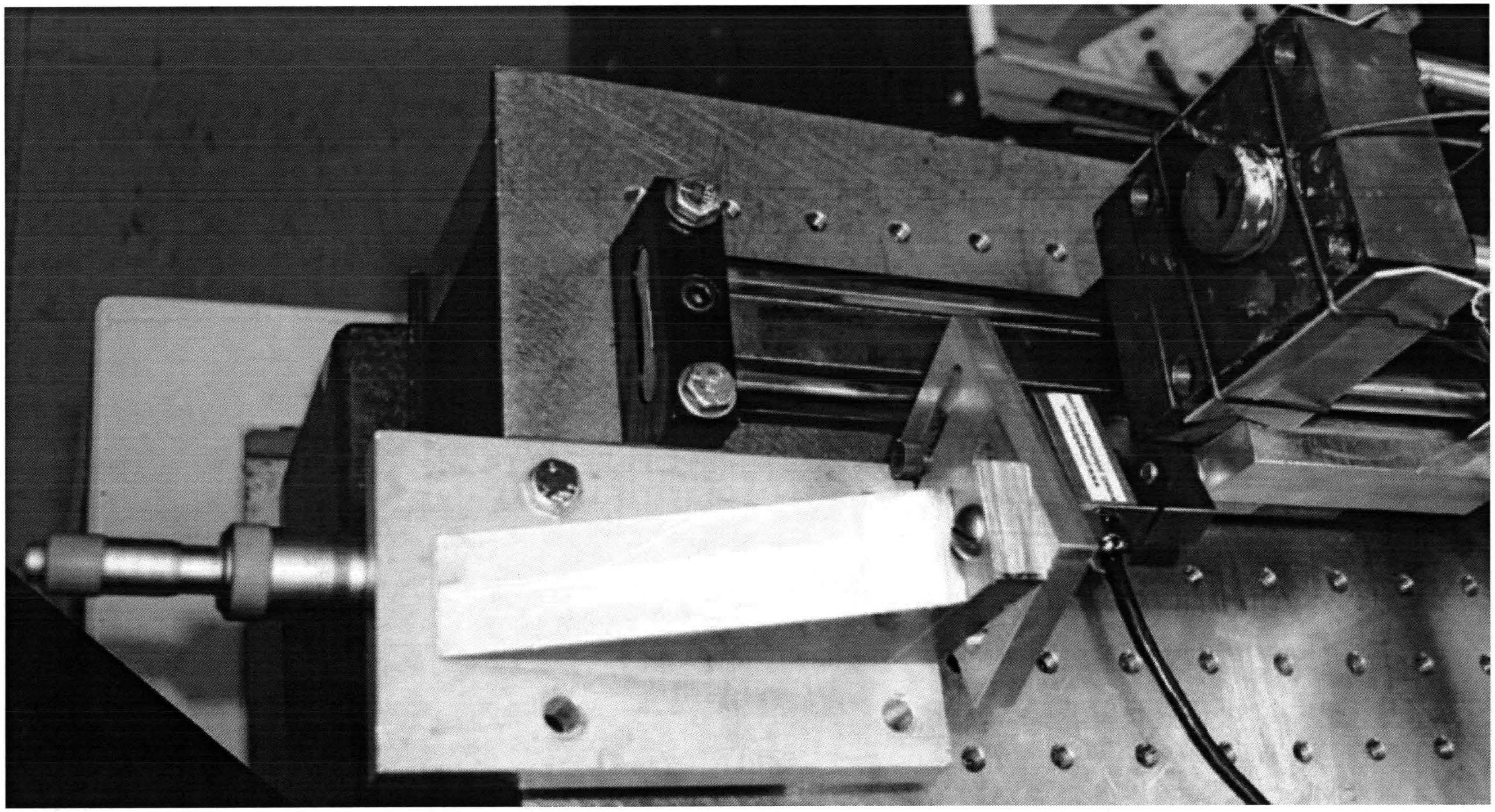




stiction force experiment setup

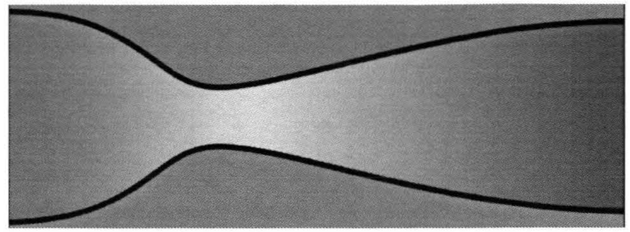
thrust measurement

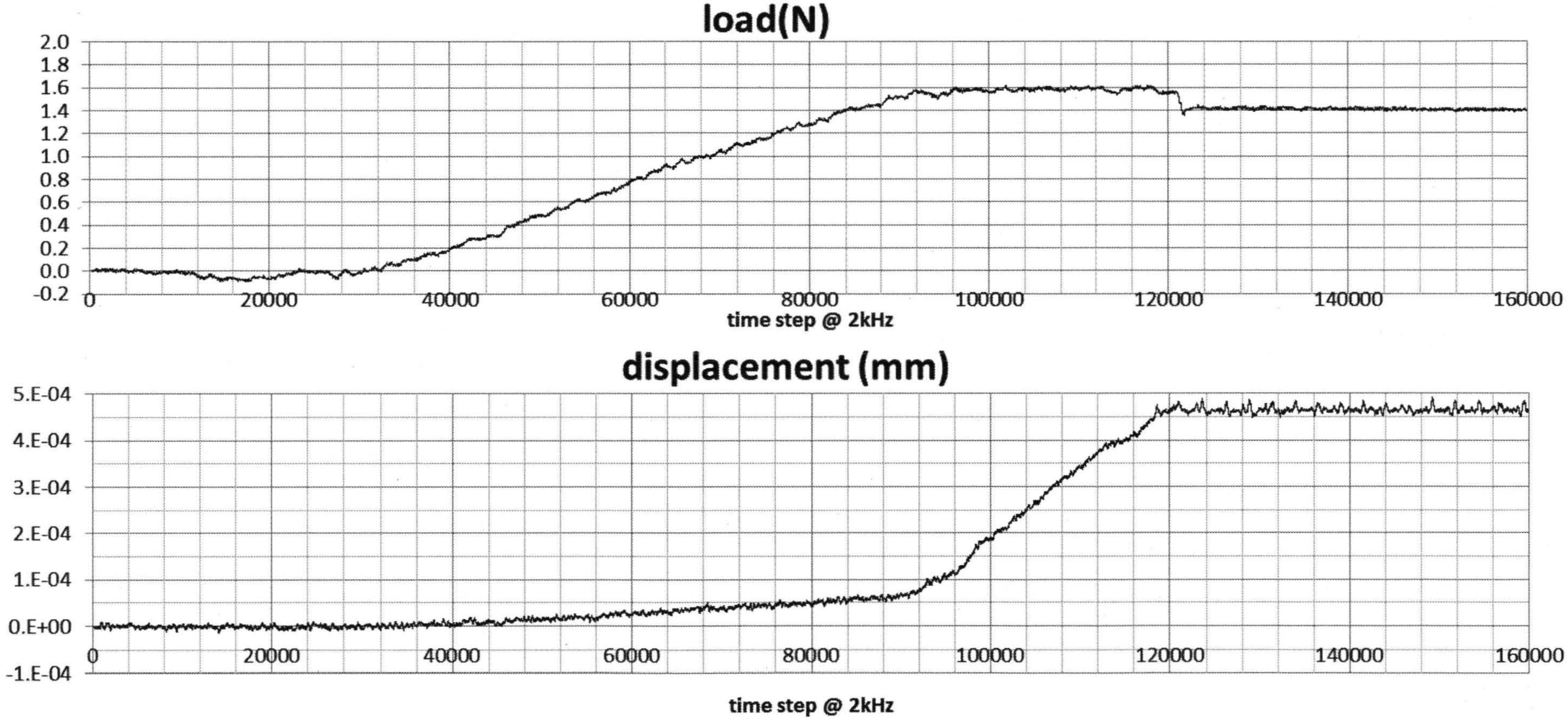




linear bearing stiction force test

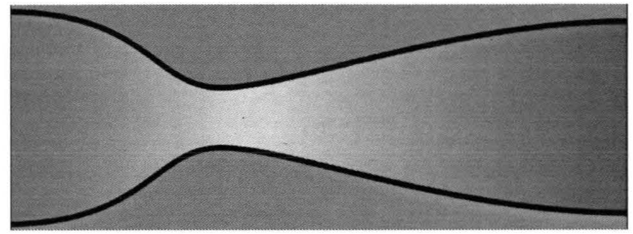
thrust measurement

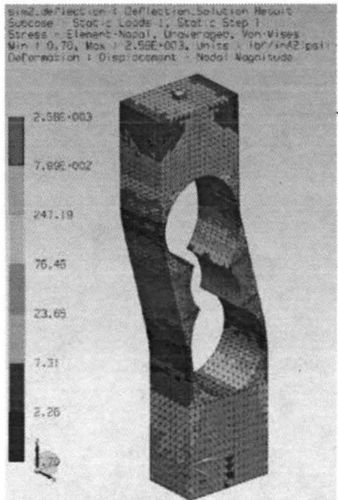




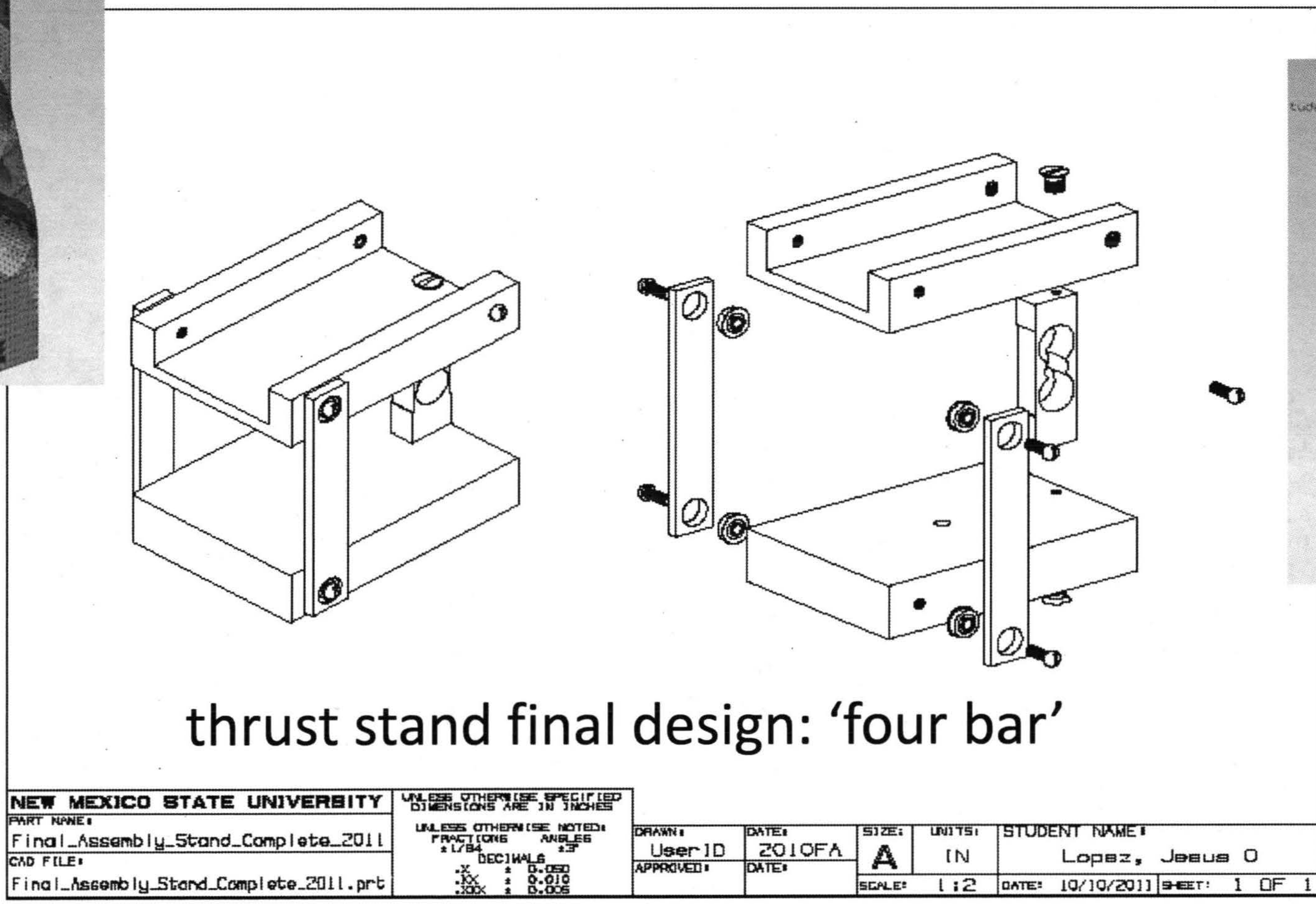
Linear bearing stiction force test results

thrust measurement

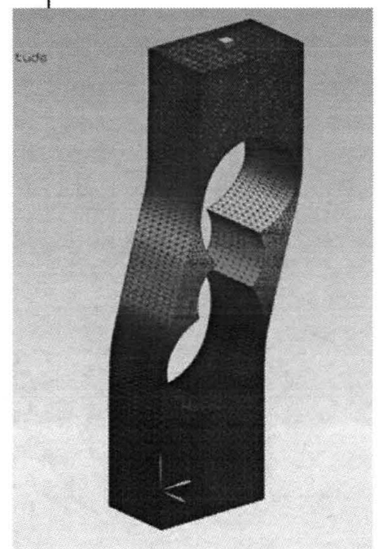




Von Mises stress

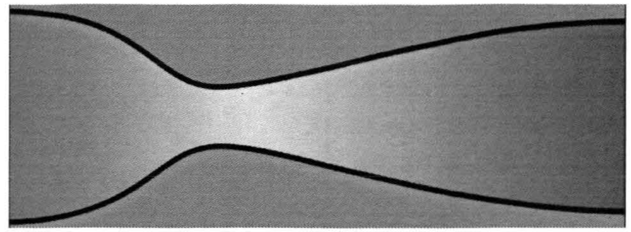


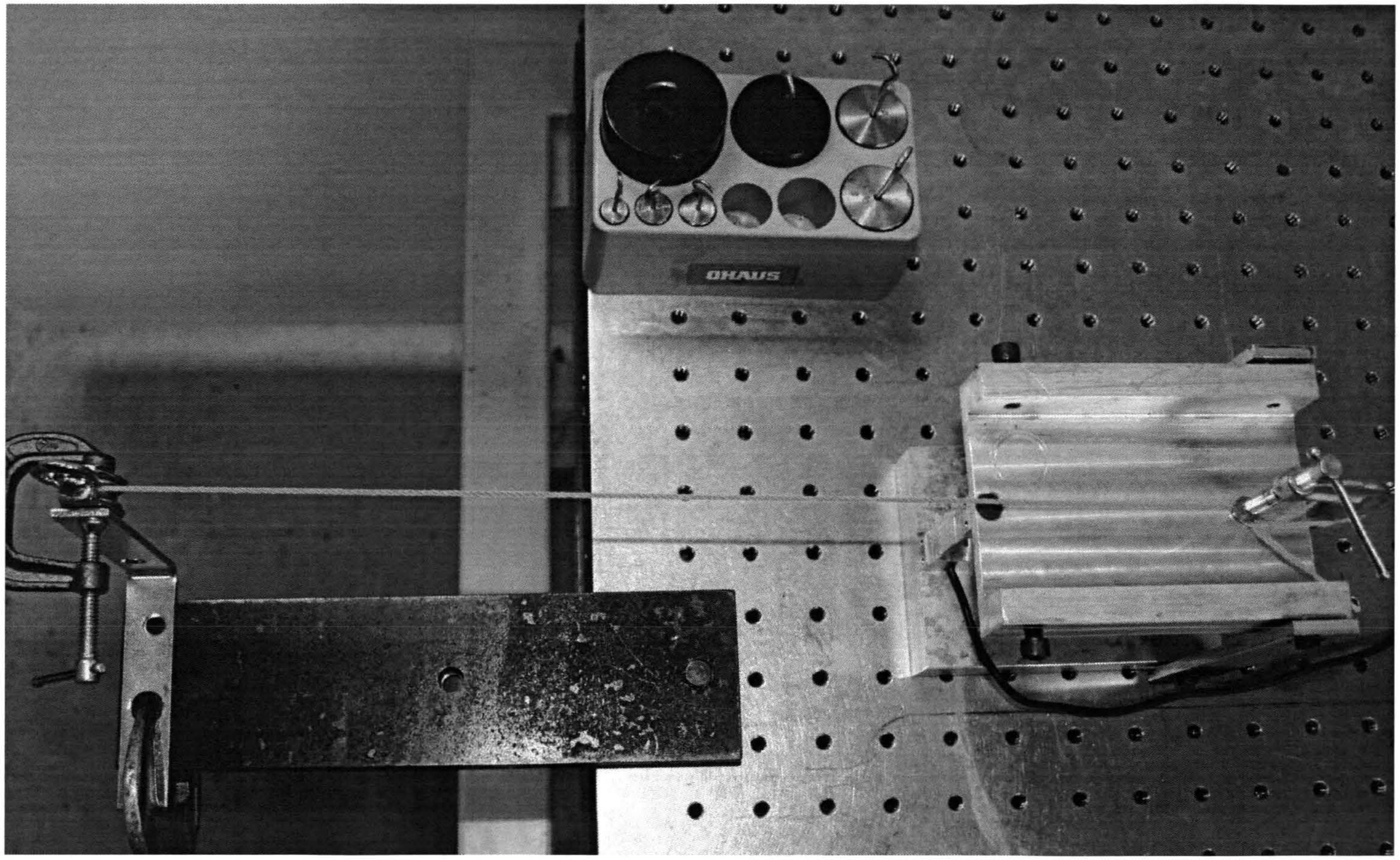
thrust stand final design: 'four bar'



load cell detail
simulation

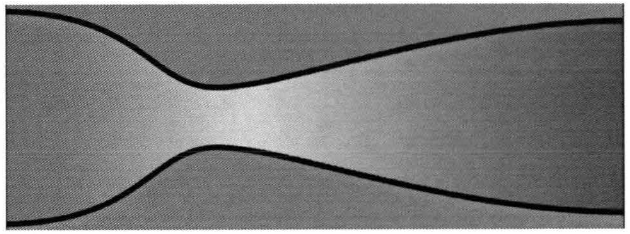
thrust measurement

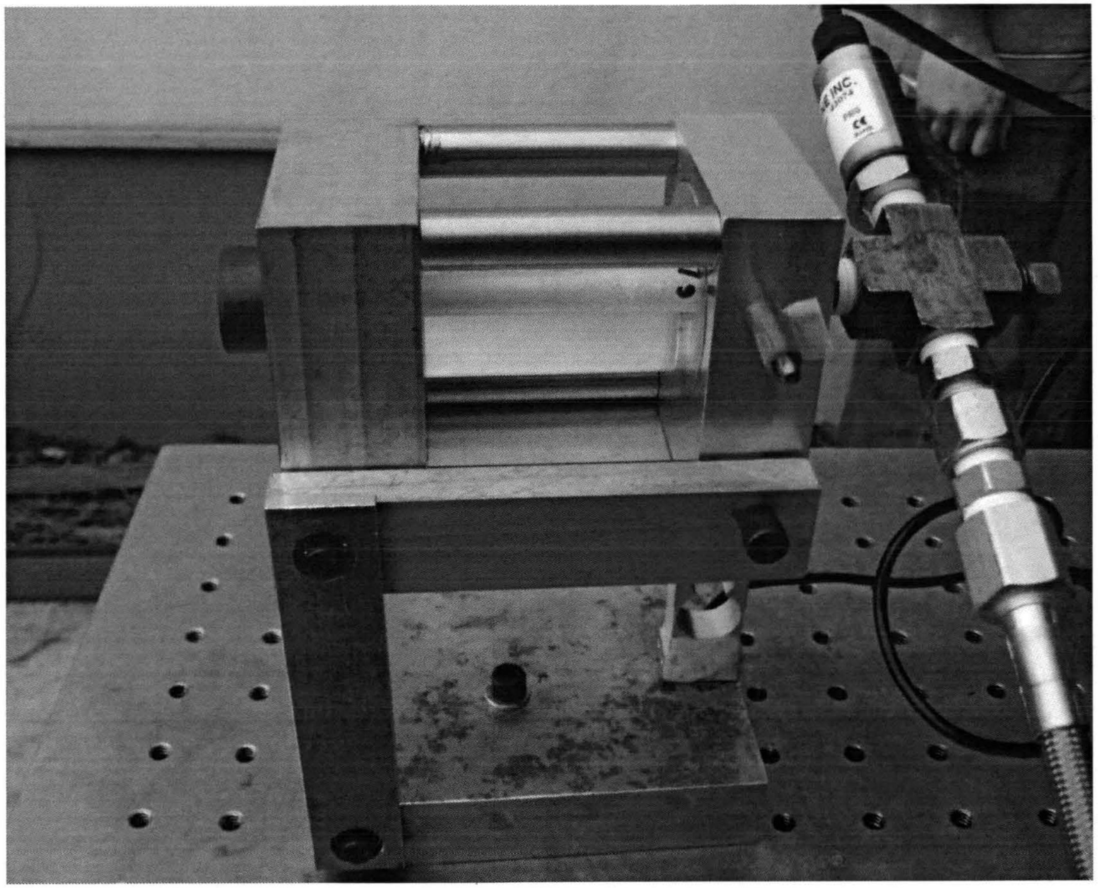


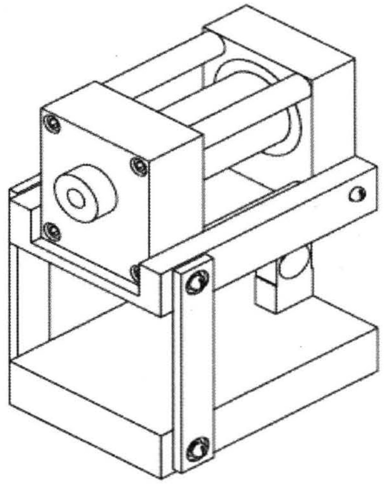


thrust stand/load cell calibration

thrust measurement

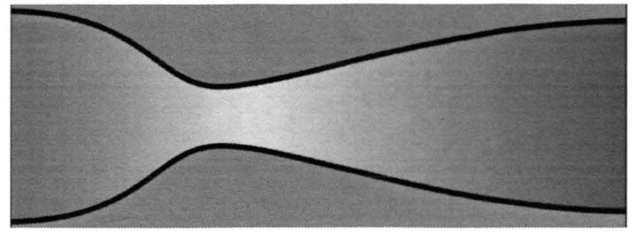


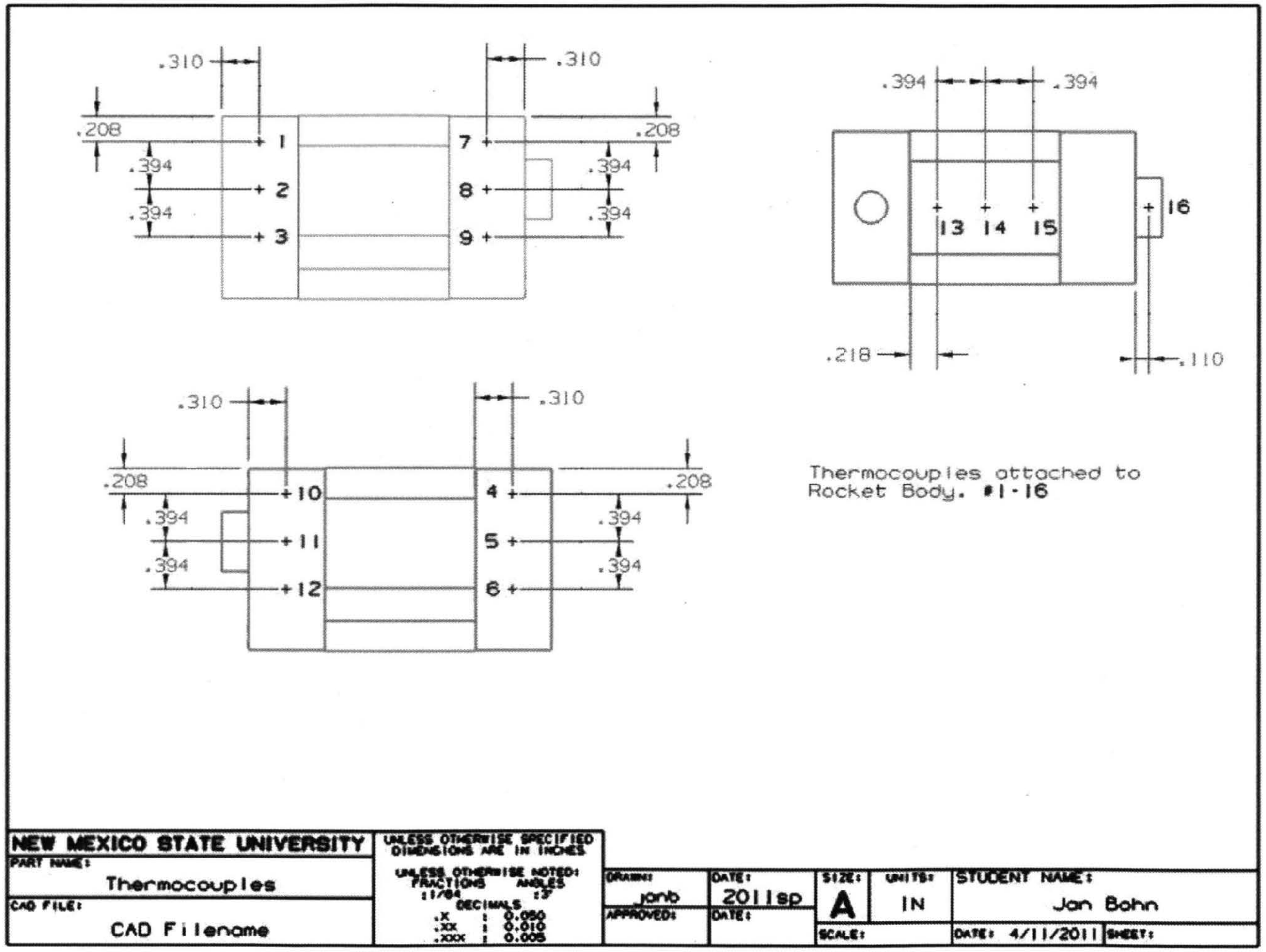




final design: thrust stand fitted with aluminum rocket body

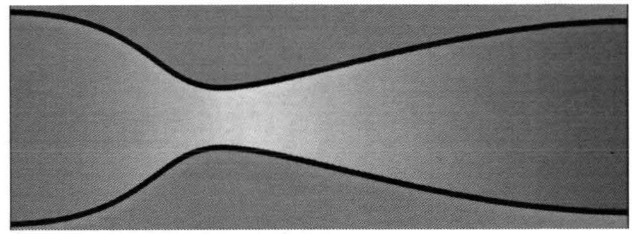
2. temperature measurement

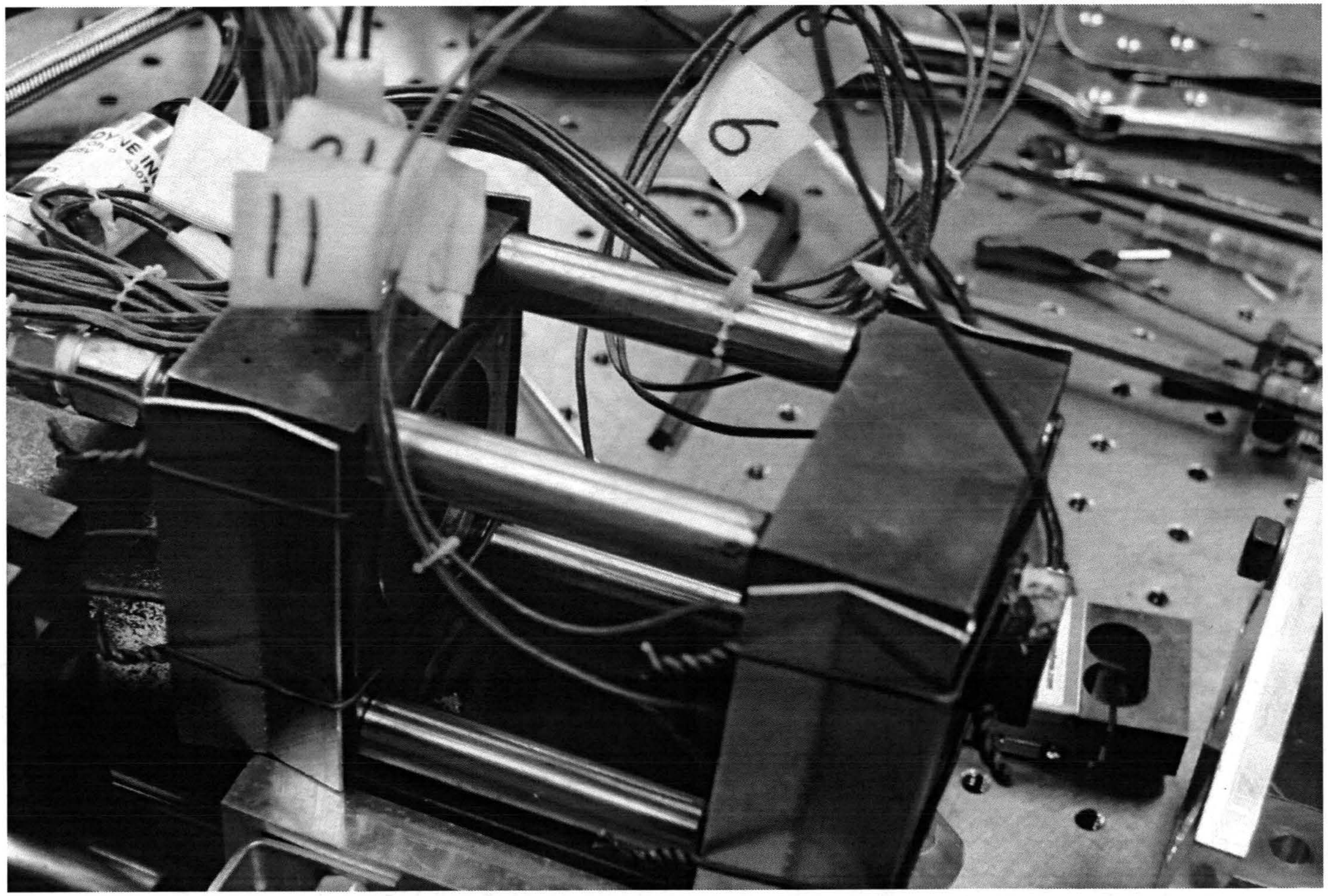




thermocouple locations

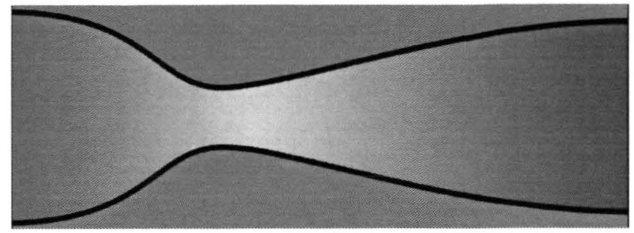
temperature measurement

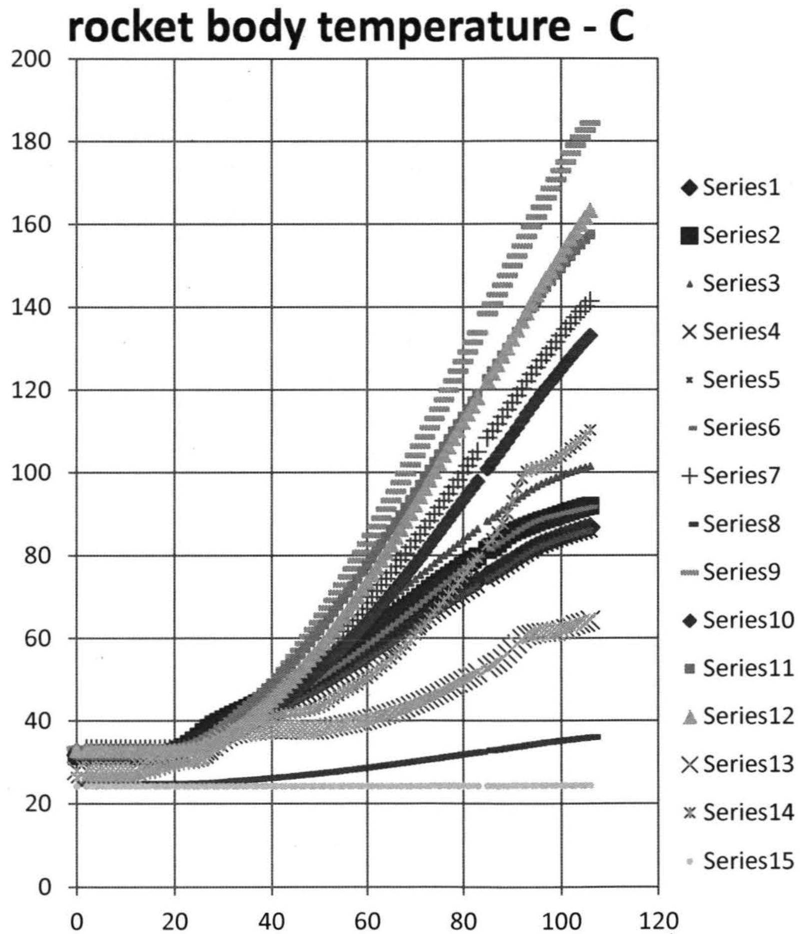


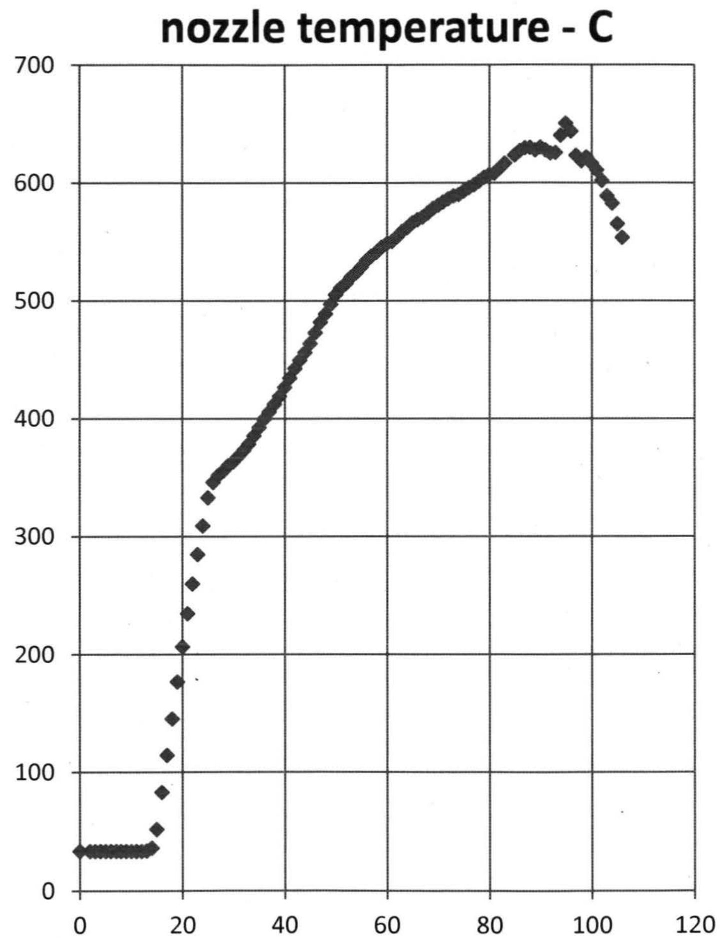


thermocouple locations

temperature measurement

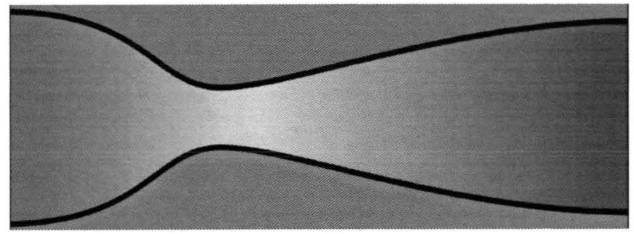


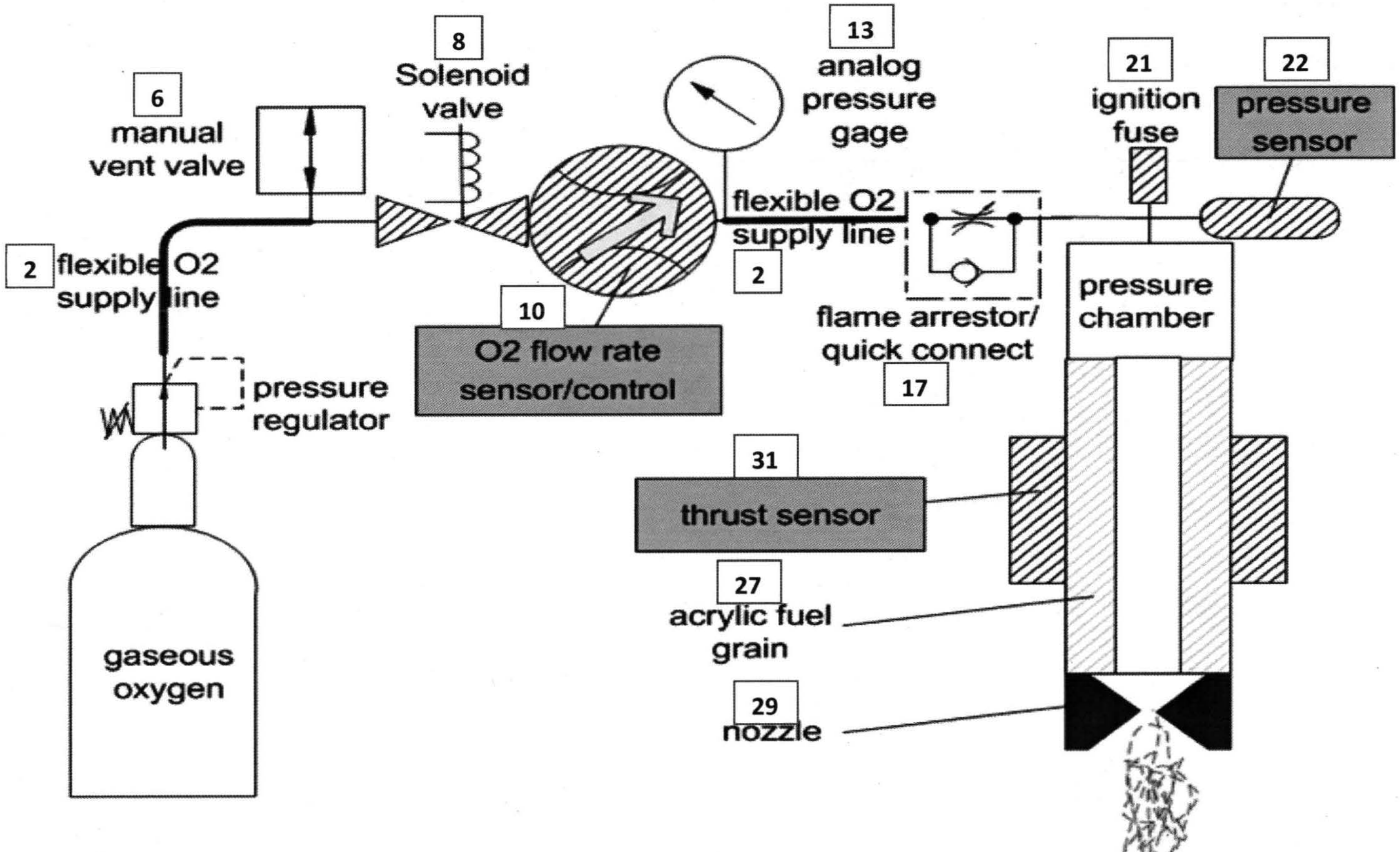




temperature vs time (sec) – steel rocket body

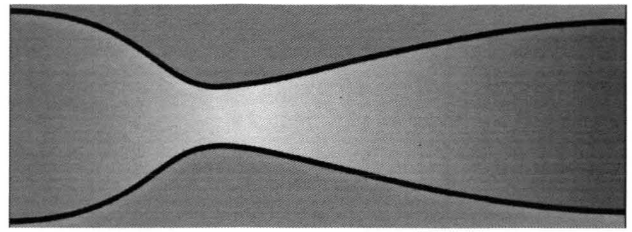
3. oxygen handling

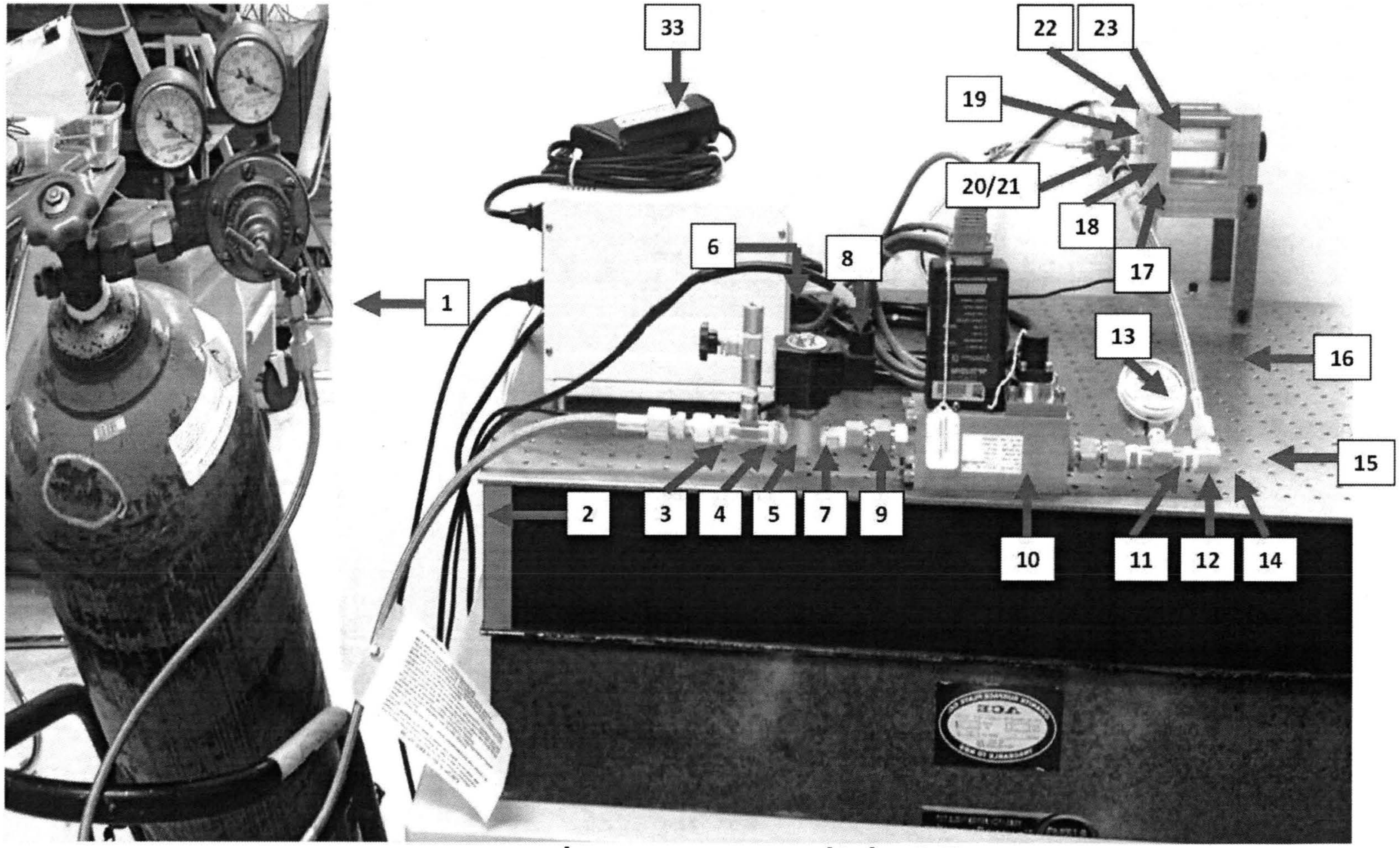




part numbers – see slide35

oxygen handling





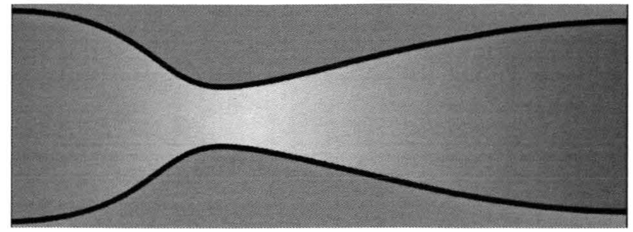
part numbers – see slide35

oxygen handling

Item#	Plumbing/Hardware Parts List Item (In Downstream Order)	No.	Quantity	Unit Price	Method of Acquirement	Cost
1	1/4" Straight Brass Regulator to Hose Coupler	1	1	$2.73	Store Purchase	$2.73
2	Female Flexible Pigtail	2	2	$33.33	Store Purchase	$66.66
3	1/4" MNPT to Compression Brass Coupler/Adapter	3	1	$3.04	Store Purchase	$3.04
4	1/4" MNPT Brass Connector	4	1	$1.92	Store Purchase	$1.92
5	1/4" FNPT Brass T-Fitting	5	1	$6.97	Store Purchase	$6.97
6	1/4" FNPT Brass Swagelok Valve	6	1	$7.48	Store Purchase	$7.48
7	1/4" MNPT Brass Connector	7	1	$1.92	Store Purchase	$1.92
8	Jefferson 1/4" FNPT Solenoid Valve	8	1	$101.95	Online Purchase	$101.95
9	1/4" MNPT Brass Connector	9	1	$1.92	Store Purchase	$1.92
10	Teledyne Hastings HFC-203 Flow Meter/Controller w/ Power Pack	10	1	$2,500.00	Online Purchase	$2,500.00
11	1/4" MNPT Brass Connector	11	1	$1.92	Store Purchase	$1.92
12	1/4" FNPT Brass T-Fitting	12	1	$6.97	Store Purchase	$6.97
13	10psi Analog Pressure Gauge	13	1	$8.83	Store Purchase	$8.83
14	1/4" MNPT Brass Connector	14	1	$1.92	Store Purchase	$1.92
15	1/4" FNPT to MStraight Brass 90 Degree Fitting	15	1	$1.57	Store Purchase	$1.57
16	Female Flexible Pigtail	16	1	$33.33	Store Purchase	$33.33
17	1/4 " Torch to Hose Quick Connect Set	17	1	$63.26	Store Purchase	$63.26
18	1/4" MNPT Brass Connector	18	1	$1.92	Store Purchase	$1.92
19	1/4" FNPT Brass Cross Fitting	19	1	$5.53	Store Purchase	$5.53
20	1/4" NPT Brass Barb Hose Adapter	20	1	$3.32	Store Purchase	$3.32
21	Aerotech First Fire Ignitor Jr. (Fuse 3 Pack)	21	1	$9.99	Online Purchase	$9.99
22	Omega Pressure Transducer PX309-030G5V	22	1	$225.00	Online Purchase	$225.00
23	1/4" MNPT Brass Connector	23	1	$1.92	Store Purchase	$1.92
24	3"x12"x1.5" 6061 Aluminum Billet (Engine Plates)	24	1	$39.29	Online Purchase	$39.29
25	36"X0.5"dia. 6061 Aluminum Round Stock (Engine Struts)	25	1	$7.52	Online Purchase	$7.52
26	12"x2"dia. General Purpose Steel Round Stock (Diffuser Plate)	26	1	$34.70	Online Purchase	$34.70
27	72"x1.5" Extruded Acrylic Round stock (Fuel Grain)	27	1	$55.43	Online Purchase	$55.43
28	6"x6"x1/16" PTFE Teflon Sheet (Interior O-Ring)	28	1	$17.25	Online Purchase	$17.25
29	12"x1.5"dia. Graphite Round Stock (Nozzle)	29	1	$78.47	Online Purchase	$78.47
30	5"x12"x1" 6061 Aluminum Billet (Test Stand Plates)	30	1	$43.87	Online Purchase	$43.87
31	Omega 1.5lb Single Point Load Cell	31	1	$136.00	Online Purchase	$136.00
32	6'x12"x0.25" 6061 Aluminum plate (Test Stand Arms)	32	1	$16.02	Online Purchase	$16.02
33	Remote Starter Switch ("Deadman" Switch)	33	1	$12.99	Store Purchase	$12.99
34	Travel Case	34	1	$69.99	Store Purchase	$69.99
35	Edge Foam	35	1	$26.75	Store Purchase	$26.75
36	Smart Foam Pad	36	1	$8.99	Store Purchase	$8.99
37	Miscellaneous	37	1	$50.00	Store/ Online	$50.00
					Total	**$3,654.61**

complete plumbing parts list

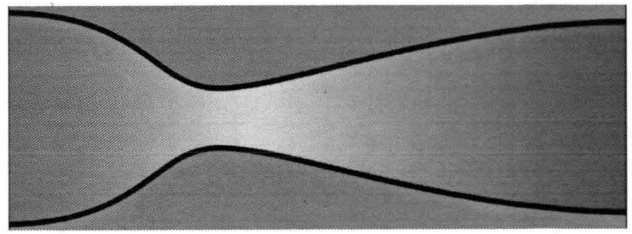
4. data acquisition & control



- system involves five analog signals:
  a. thrust – input
  b. pressure – input
  c. O_2 flow rate – input
  d. O_2 flow control – output
  e. temperature measurement - input
- flexible data rates – 10 ~ 2000Hz
- LabVIEW (National Instruments)

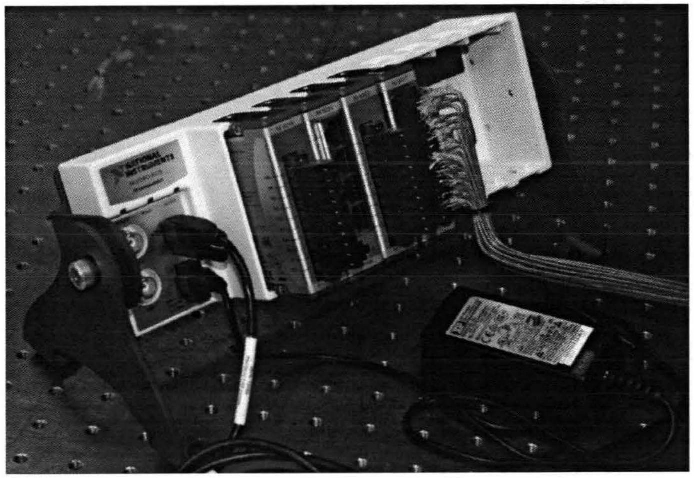
the first decision is how much $ can be spent

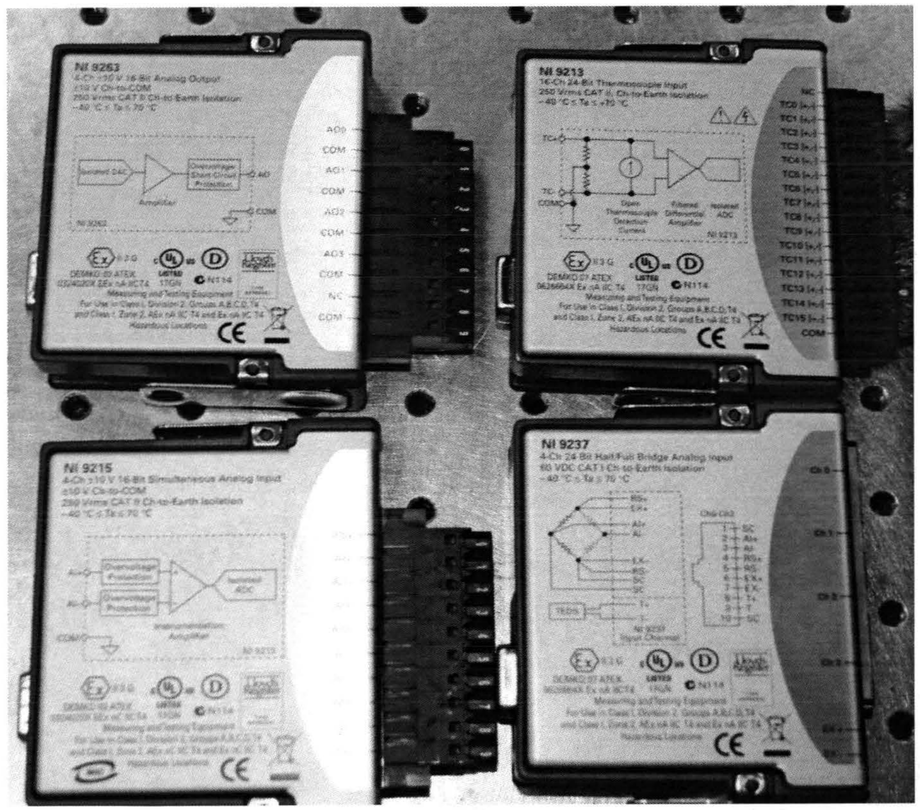
data acquisition & control



upscale option: National Instruments Compact DAQ (16 bit, usb)

http://www.ni.com/compactdaq/whatis/





NI9178 chassis+required modules:

- bridge input
- analog input
- analog output
- temperature input

total roughly $5k ~ 6k

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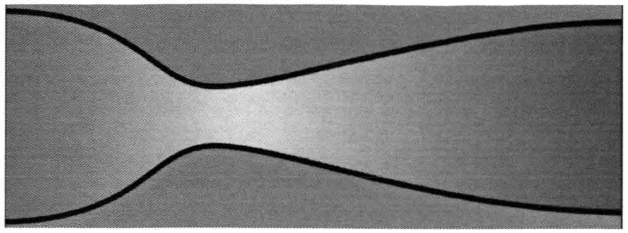
data acquisition & control

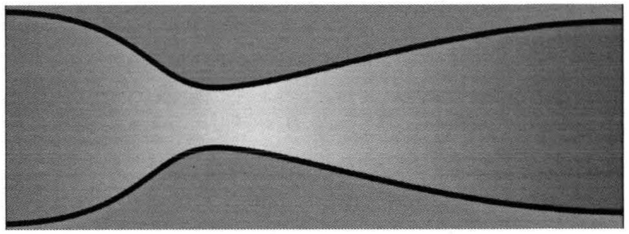


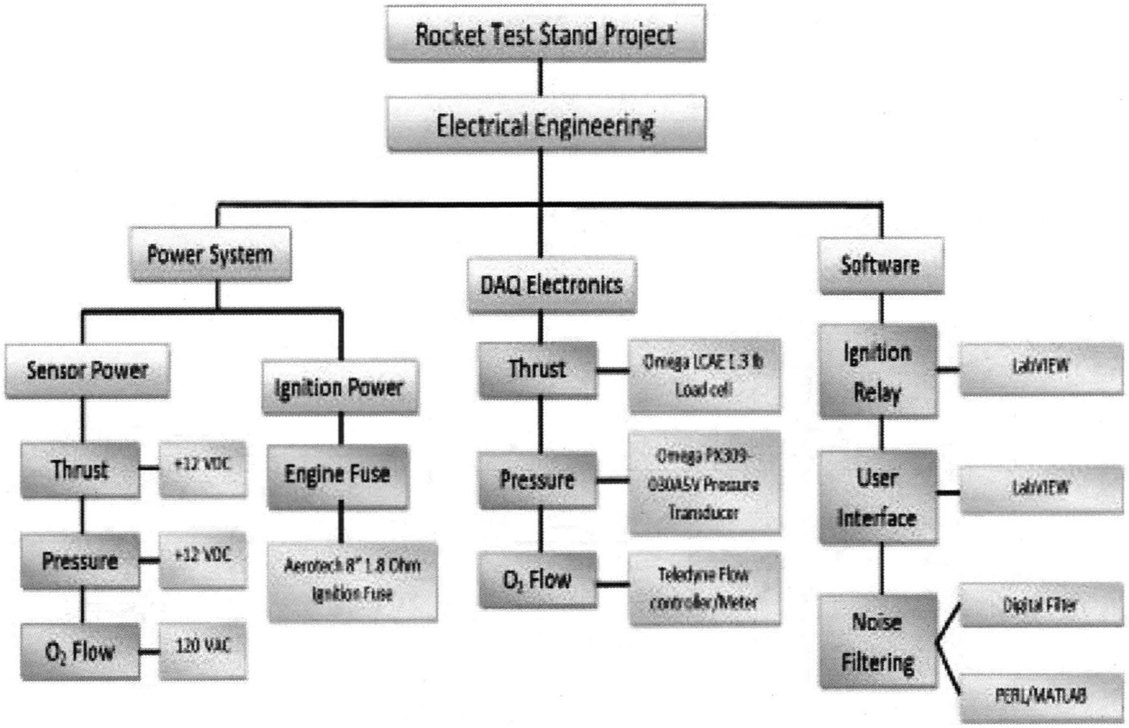
downscale option: Multifunction NI6009 (14 bit, usb)
http://sine.ni.com/nips/cds/view/p/lang/en/nid/201987

But NI6009 does not accommodate thermocouples or bridge circuits.

total roughly $300

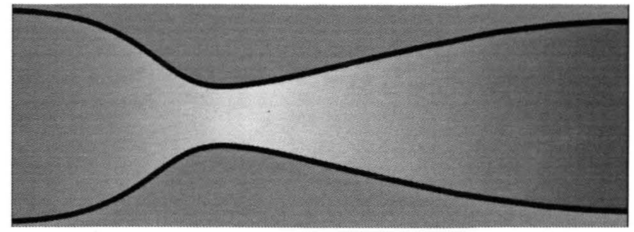
data acquisition & control

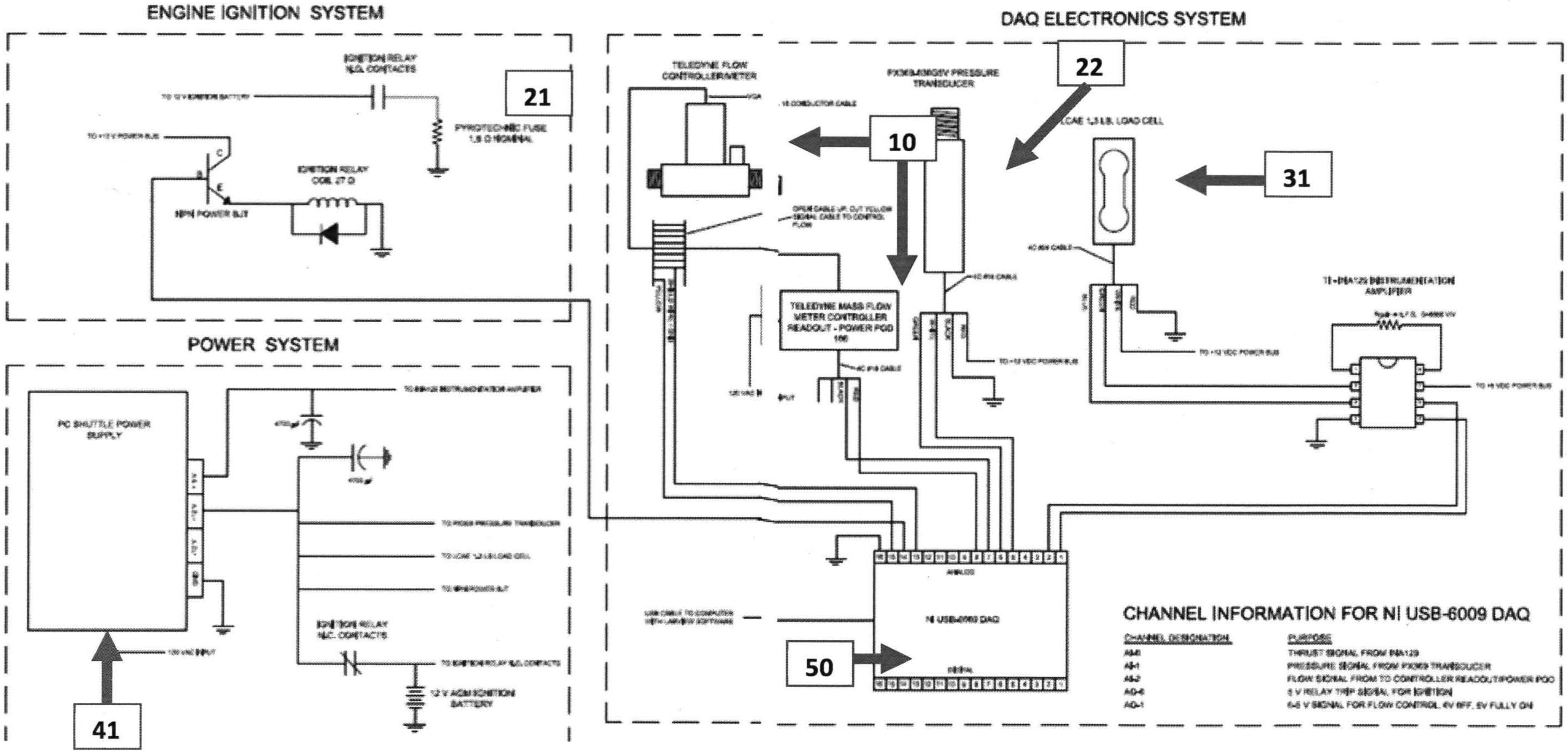




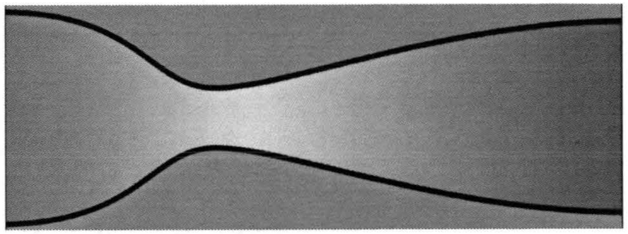
students' system concept

data acquisition & control

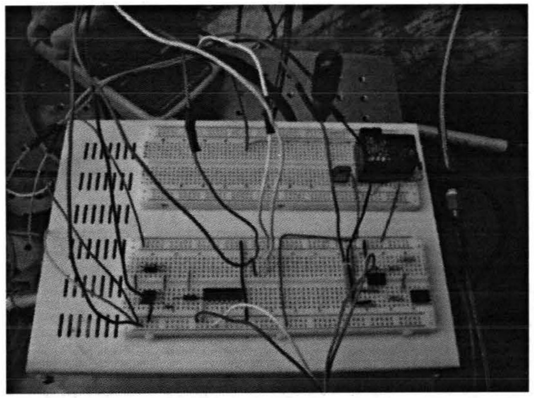




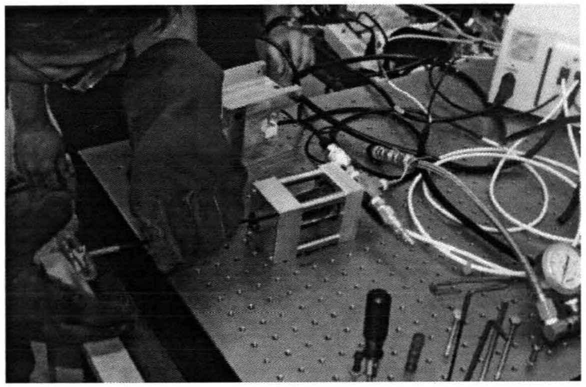
electrical schematic – see slide45

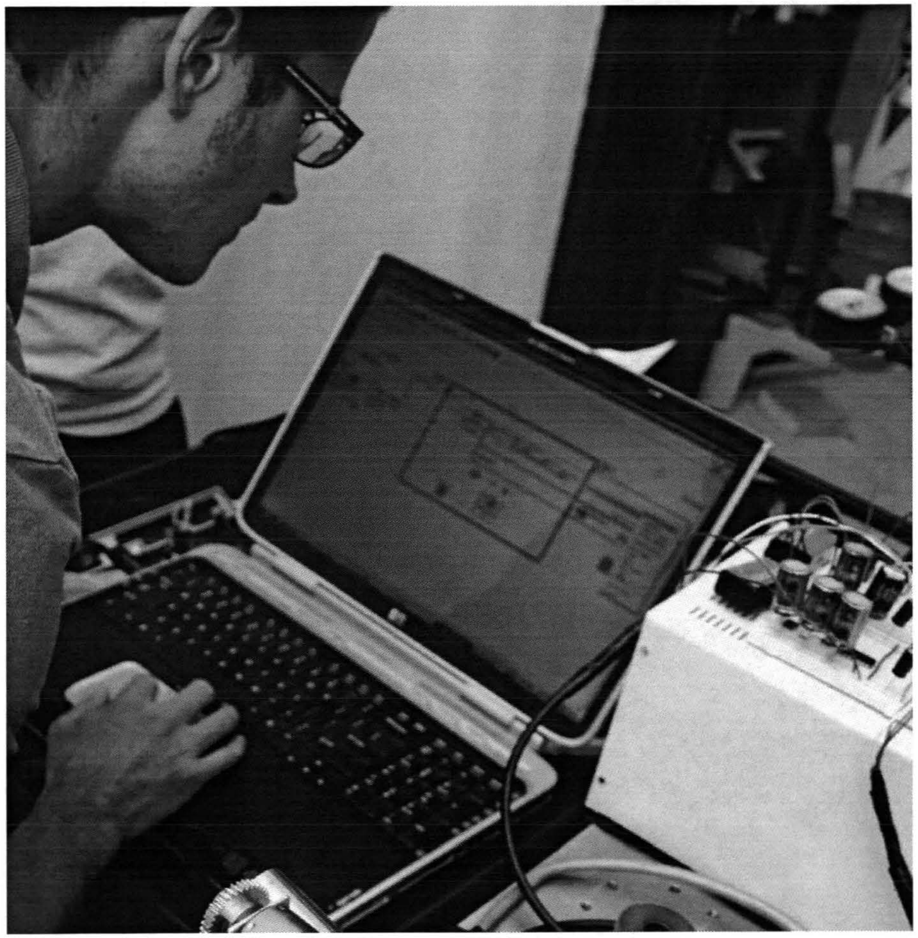


data acquisition & control



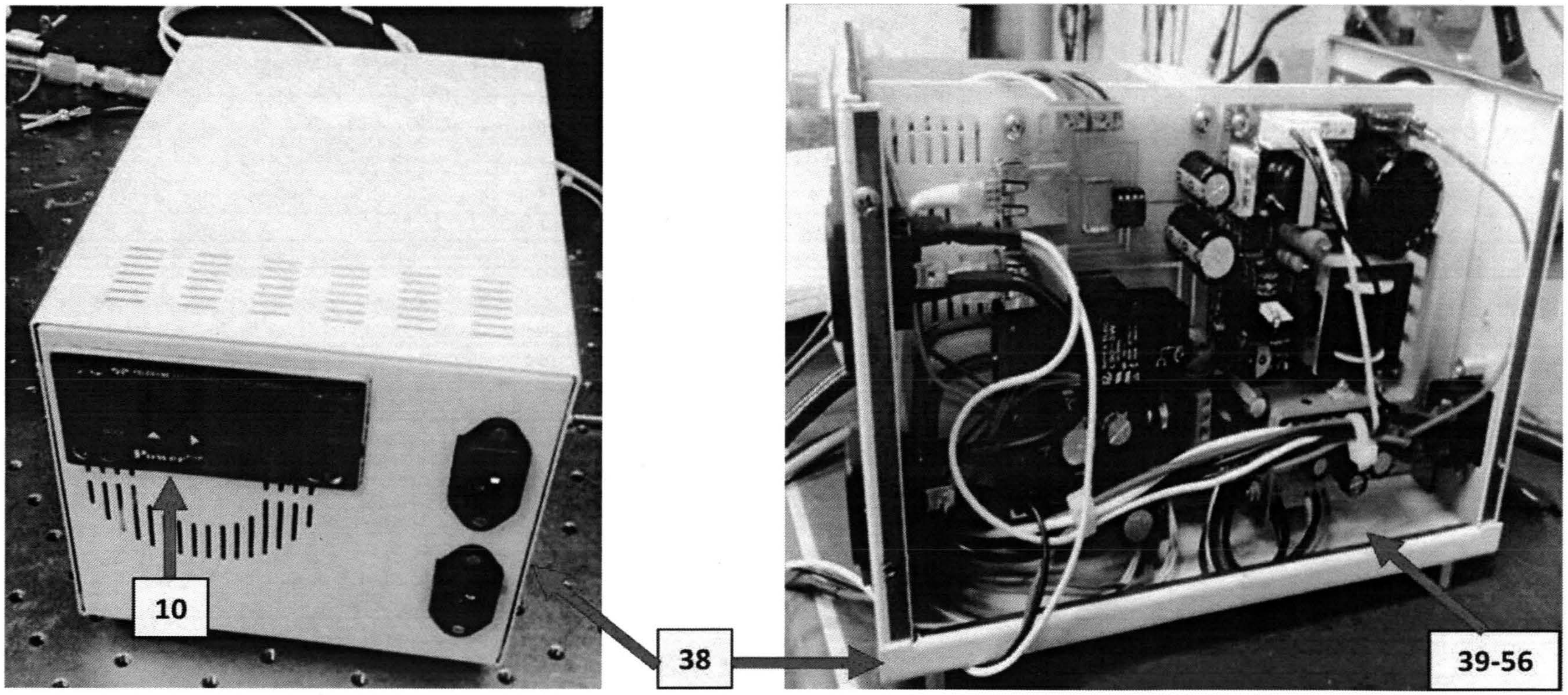
components testing





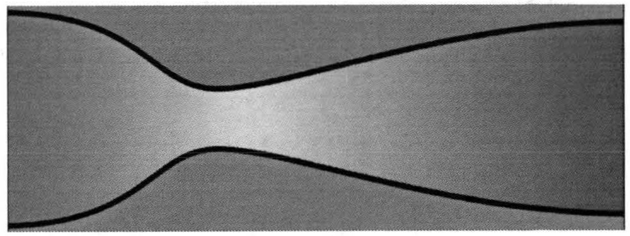
systems integration

data acquisition & control



final design: electronics hardware – see slide45

data acquisition & control



item#	Electronic Controls Parts List Item	Quantity	Unit Price	Method of Acquirement	Cost
38	Electronics Case	1	$10.00	Store Purchase	$10.00
39	9V Rechargable Battery	2	$9.00	Store Purchase	$18.00
40	12V UPS Battery	1	$27.23	Store Purchase	$27.23
41	Digital Power Supply	2	$76.30	Online Purchase	$152.60
42	PCB Designs Boards	4	$45.00	Online Purchase	$180.00
43	Operational Amplifiers	10	$8.00	Online Purchase	$80.00
44	Rectifying Diodes	2	$2.50	Online Purchase	$5.00
45	Filtering Capacitors	1	$5.00	Online Purchase	$5.00
46	Voltage Regulators	4	$3.50	Online Purchase	$14.00
47	Calex Digital Converter	1	$124.00	Online Purchase	$124.00
48	250V 5A Relay	1	$10.00	Online Purchase	$10.00
49	TIP Power BJT	2	$3.49	Store Purchase	$6.98
50	National Instruments USB-6009 DAQ	1	$279.00	Online Purchase	$279.00
51	National Instruments LabVIEW Software	1	$3,195.62	Online Purchase	$3,195.62
52	CAT5e Cable (20')	1	$11.43	Store Purchase	$11.43
53	RJ45 Modular Connector (M/F 6 Pack)	3	$14.40	Store Purchase	$43.20
54	6 Port Telecom. Face Plate	1	$1.98	Store Purchase	$1.98
55	Face Plate Blank (10 Pack)	1	$2.99	Store Purchase	$2.99
56	USB Cable	2	$6.99	Store Purchase	$13.98
57	Miscellaneous	1	$50.00	Store/Online	$50.00
				Total	**$4,231.01**

complete electronics parts list

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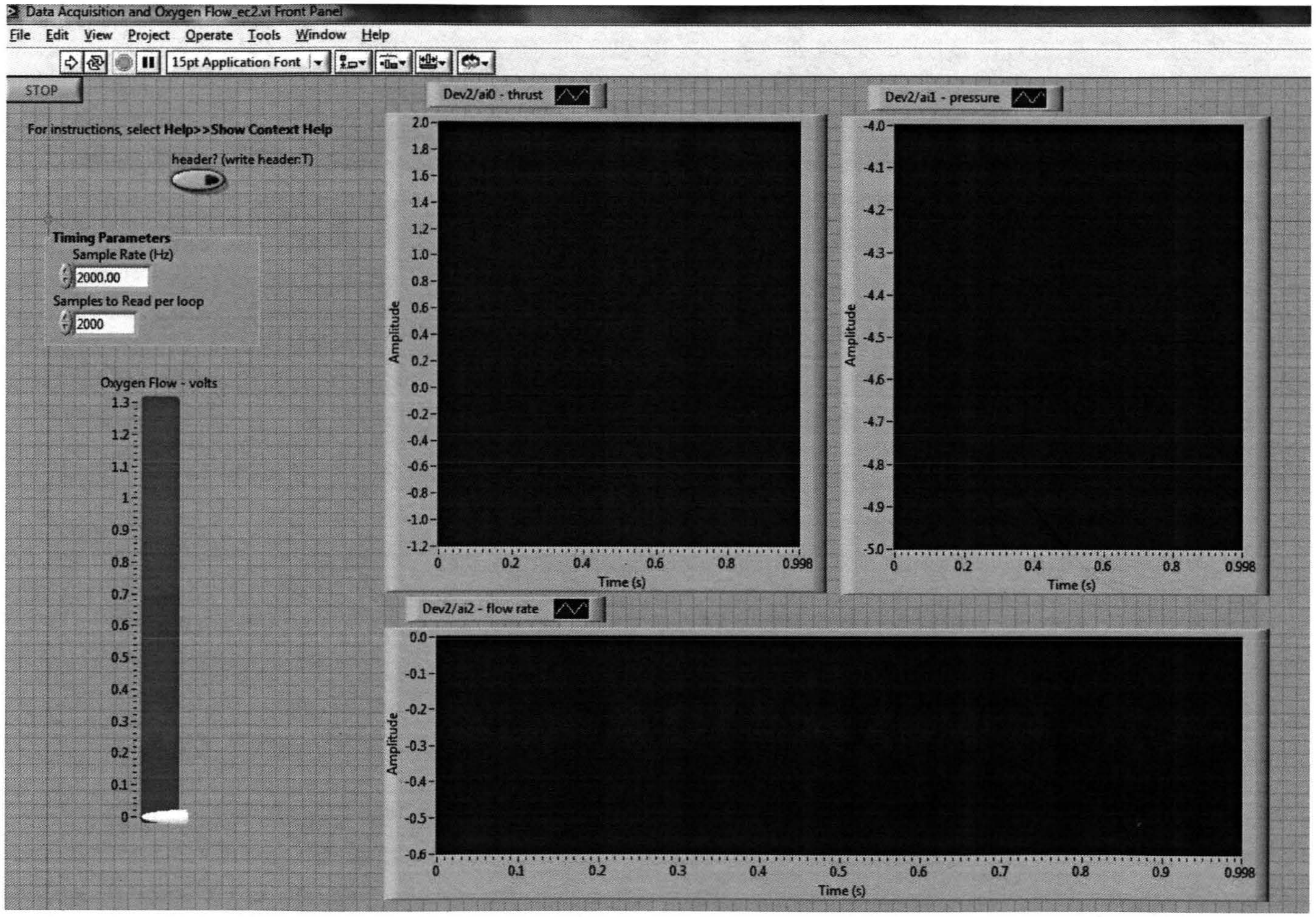
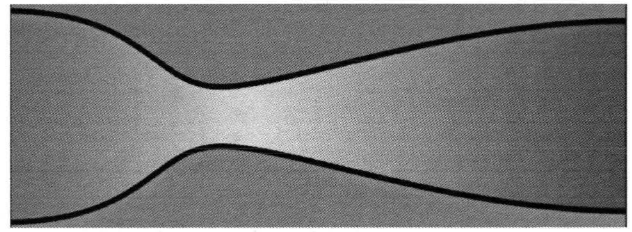
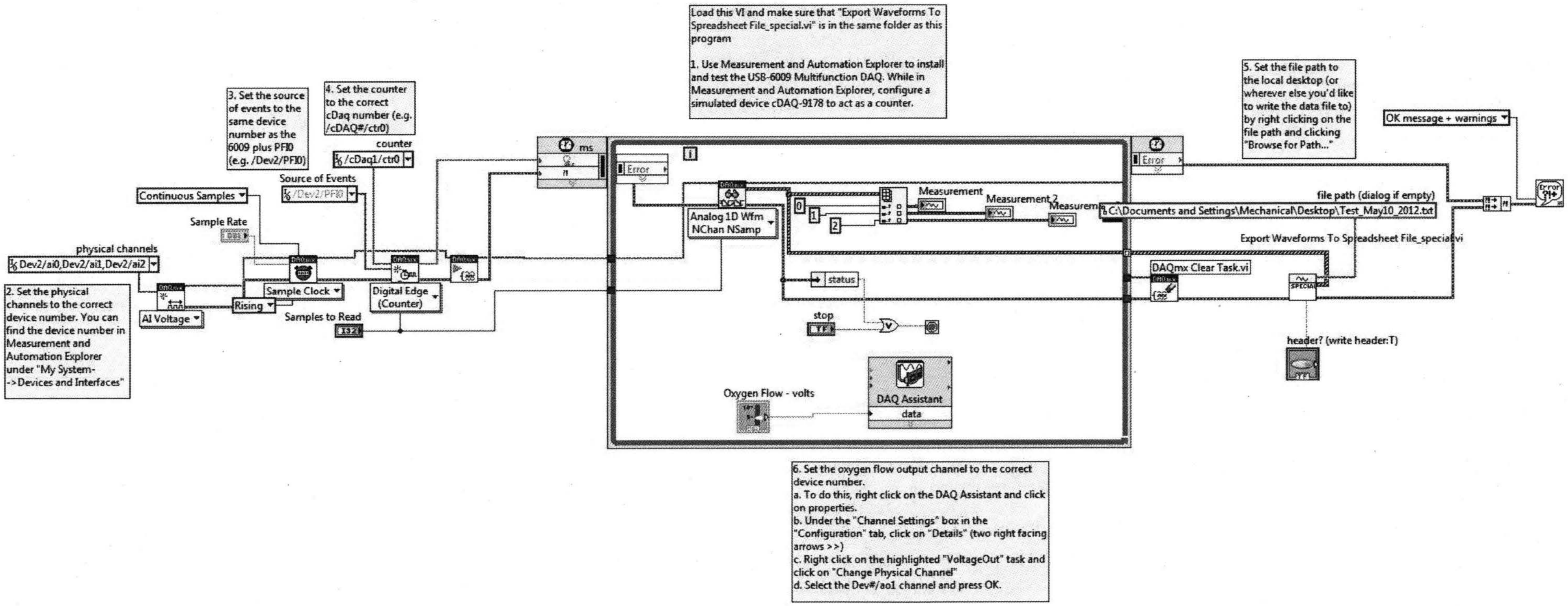
data acquisition & control



LabVIEW data acquisition & O2 flow control – front panel

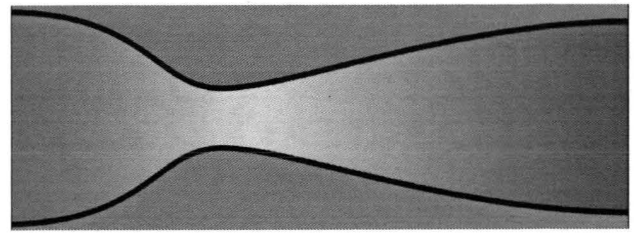
data acquisition & control

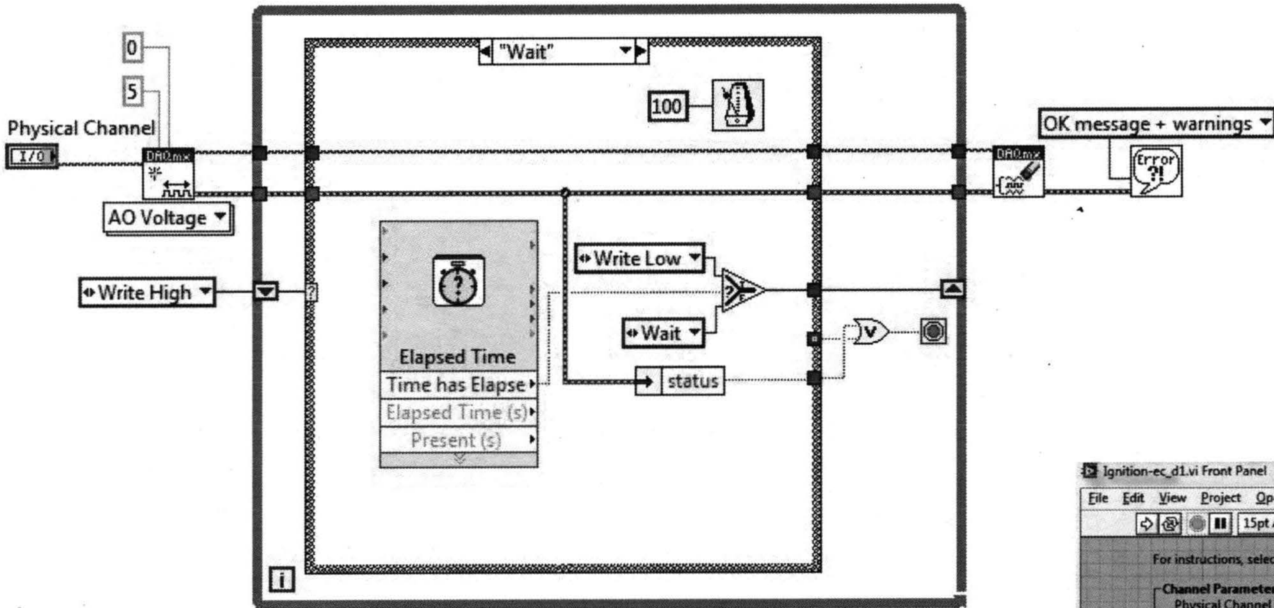




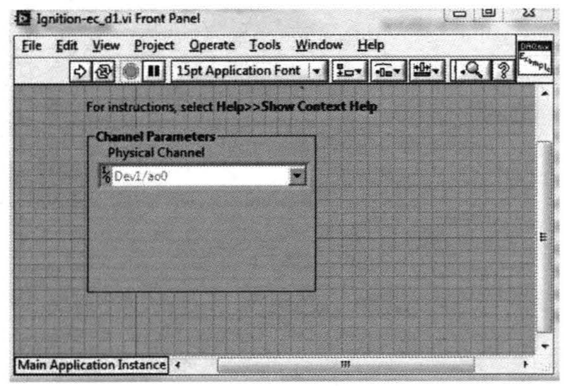
LabVIEW data acquisition & O2 flow control – block diagram

data acquisition & control

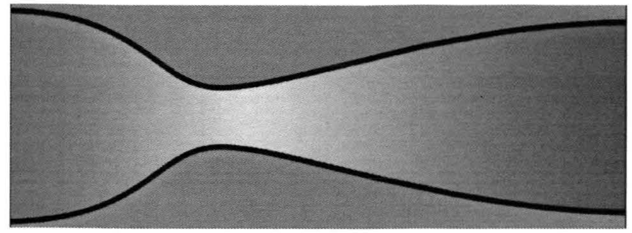




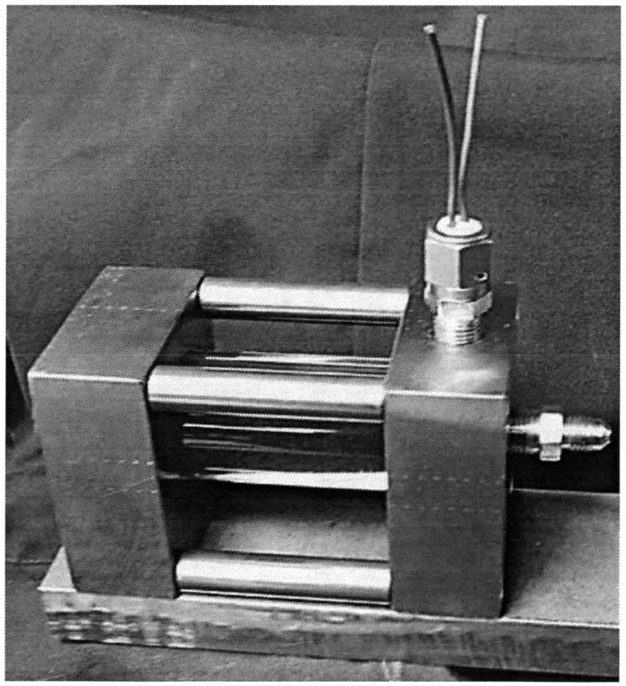
LabVIEW ignition control

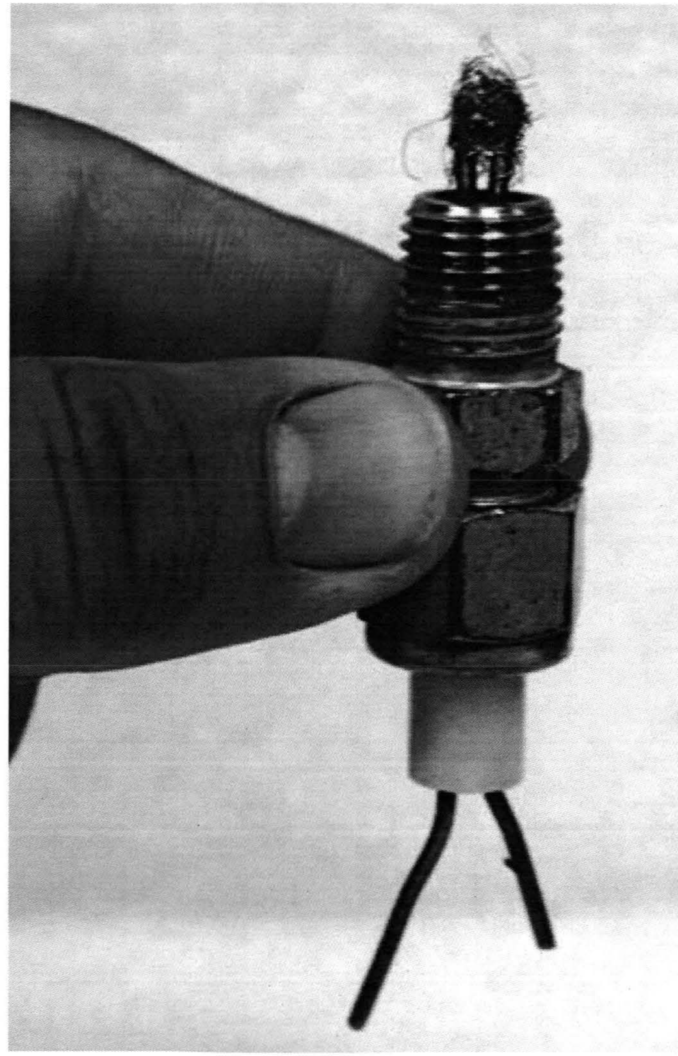


5. ignition system



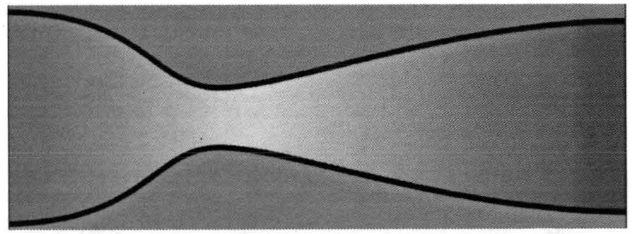
original igniter design



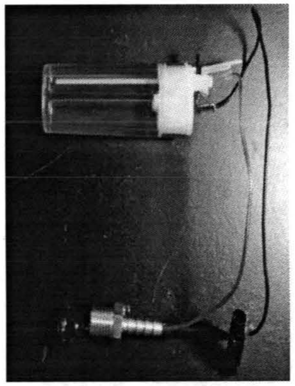


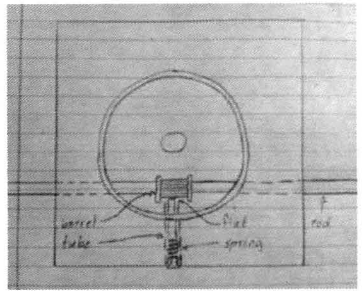
ignition system

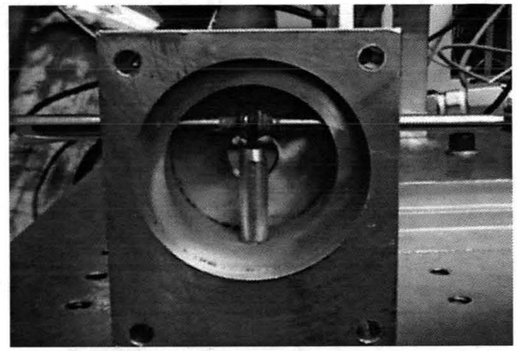
four alternative designs are described



butane ignition

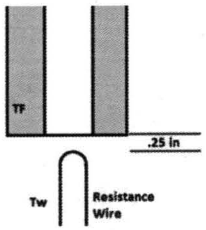




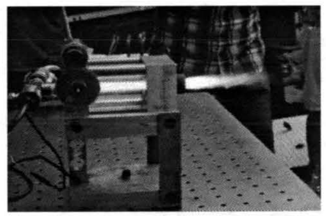


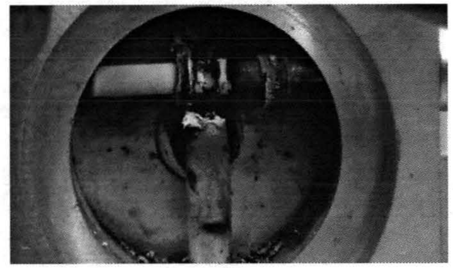
mechanical

hot wire

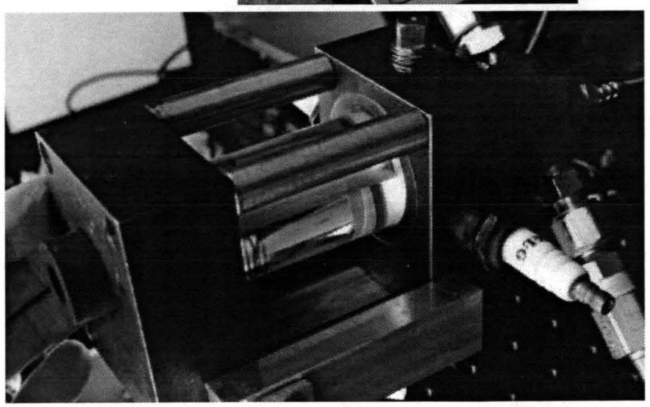


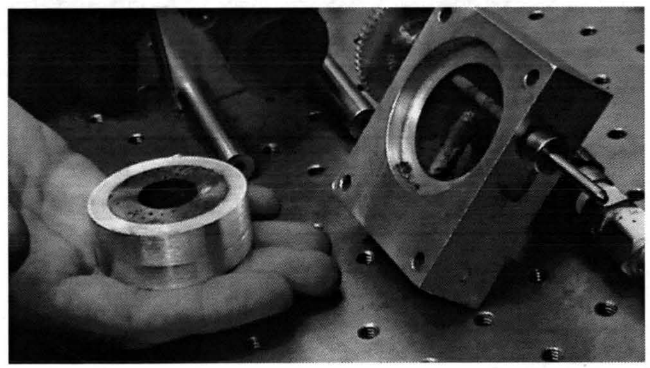
Find: The conditions at which TF >= 850° F – 1310 R



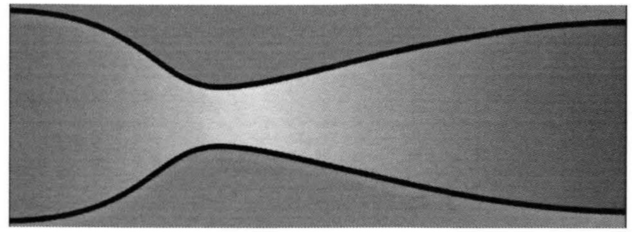


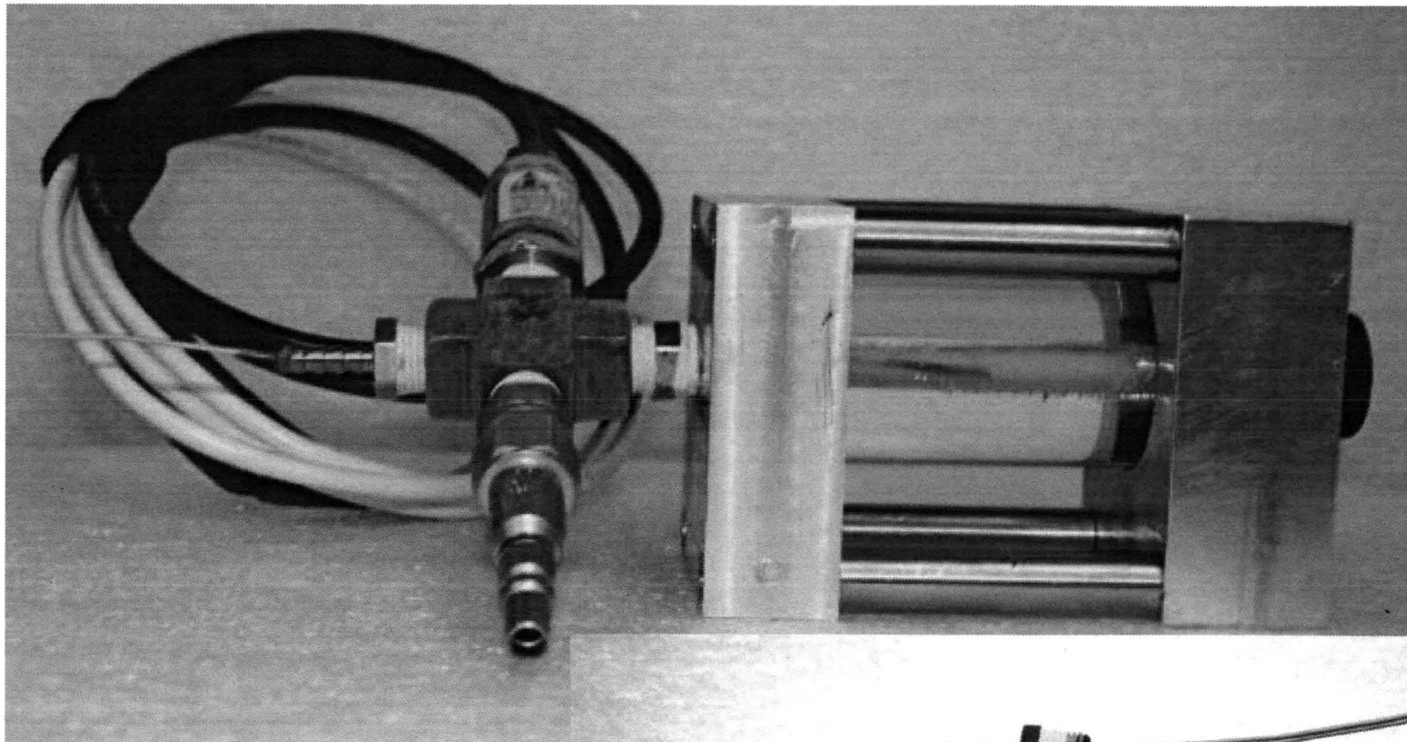
Induction coil/ spark plugs

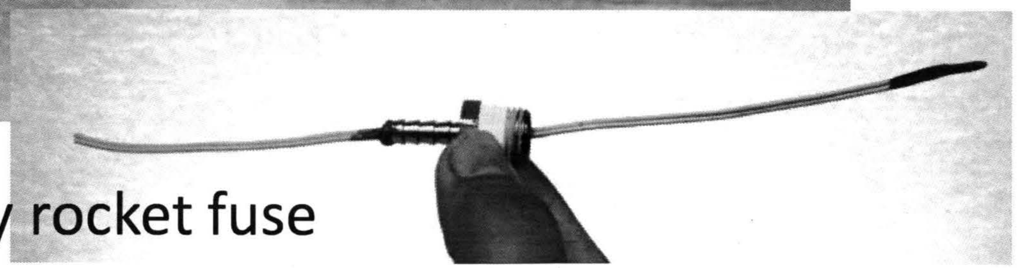




ignition system

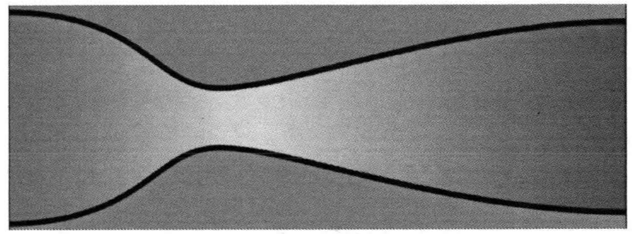






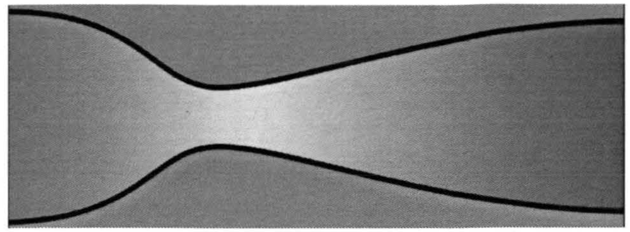
final design: hobby rocket fuse

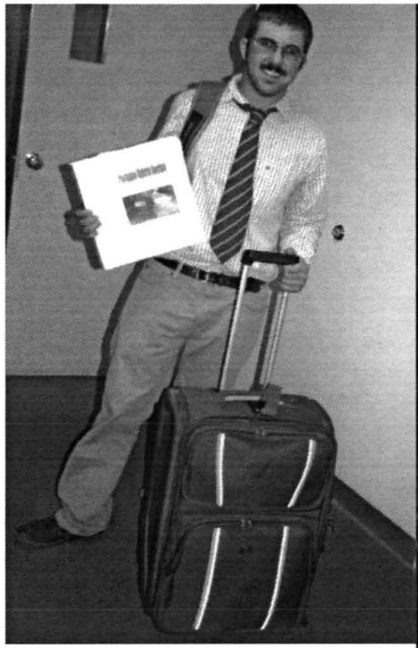
6. documentation

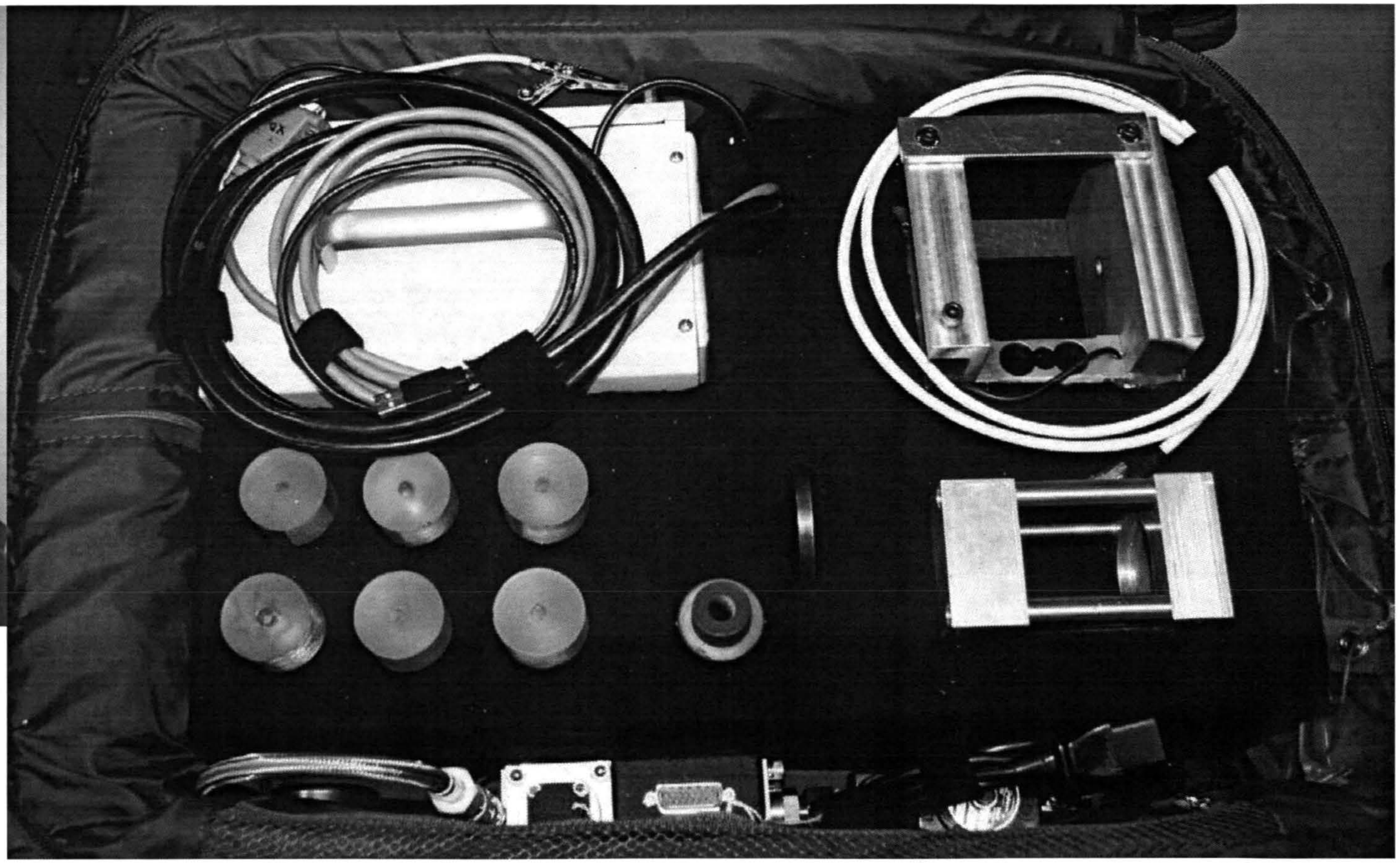


- <u>assembly instructions</u>
- <u>test procedure</u>
- <u>safety checklist</u>

7. packaging



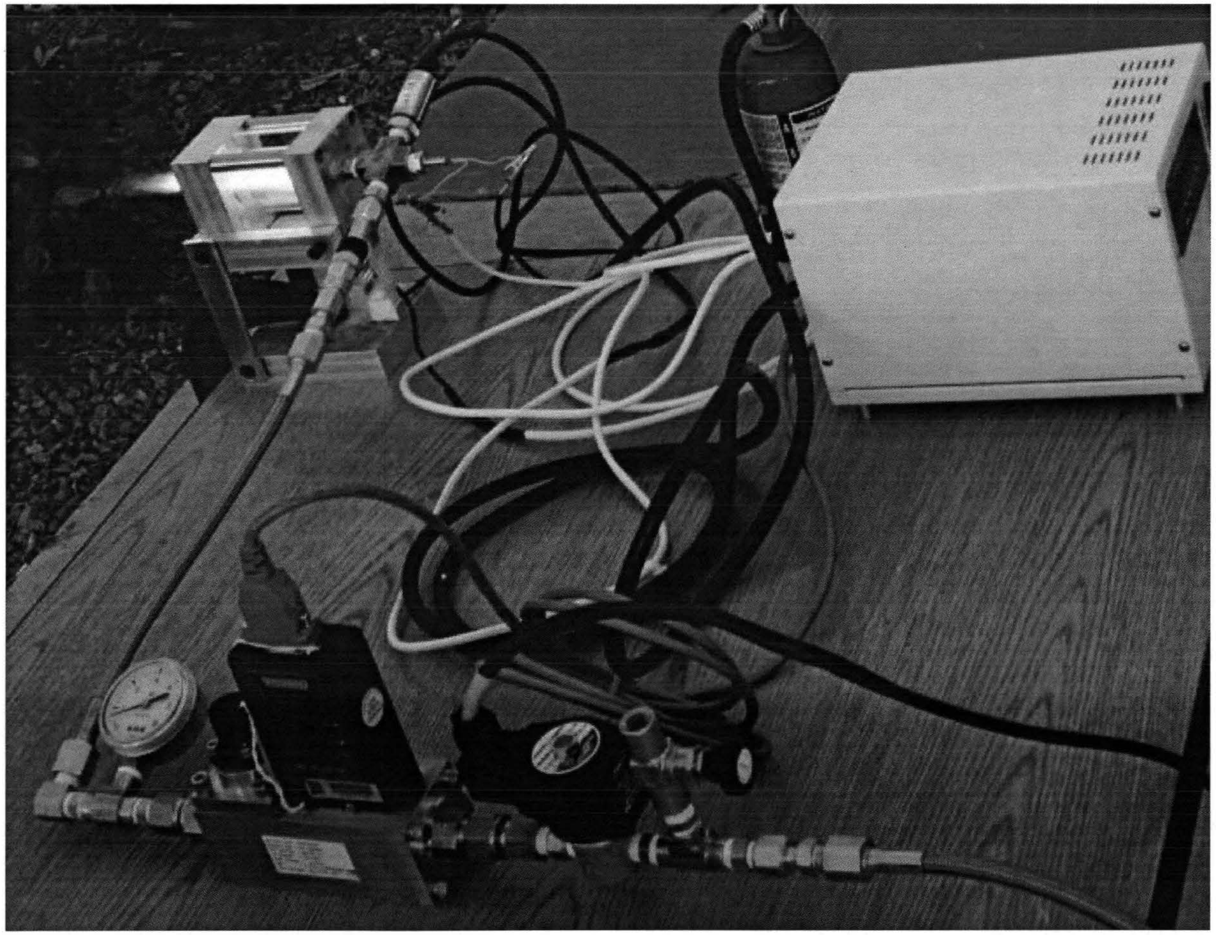




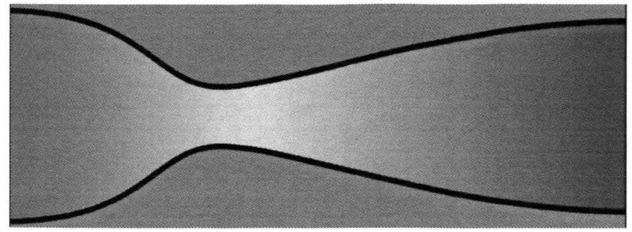
rocket to go

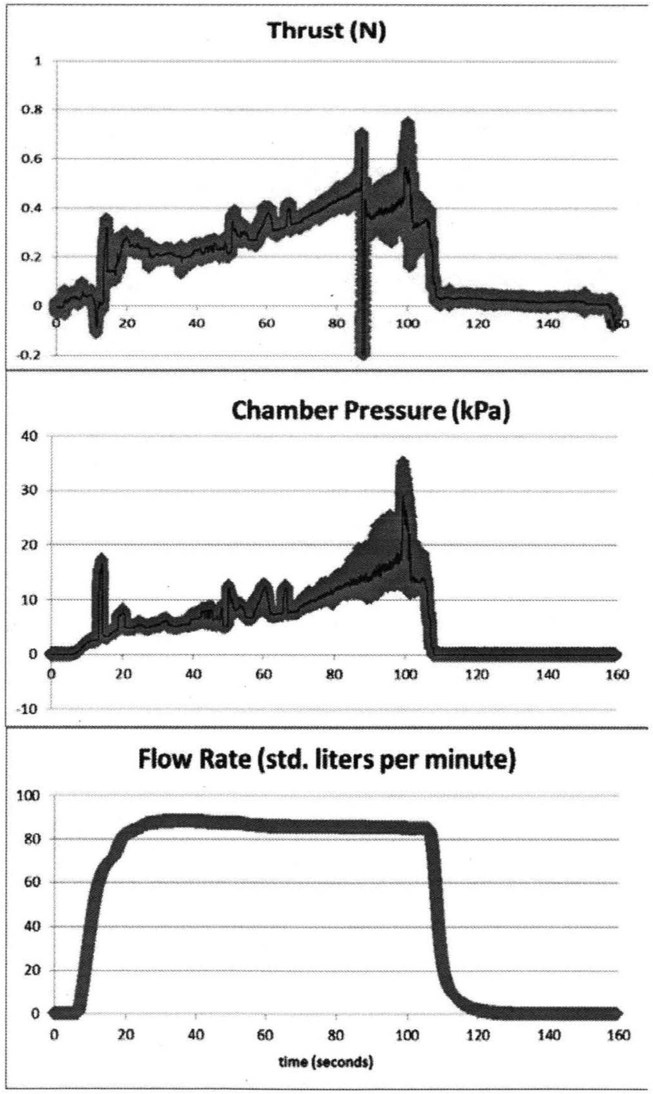
Test Stand Demonstration

Jake Valencia



typical data





lessons learned

what works

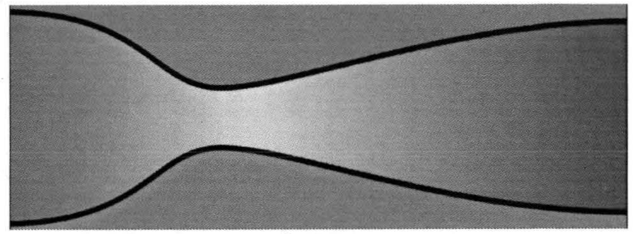
- capstone design
- a compelling topic (rocket propulsion)
- multidisciplinary teams
- weekly mentor meeting with teams and individuals
- lead engineer assignment proved valuable
- two semesters or one - flexibility has value, depending on project scope
- hybrid rocket motors - they are inexpensive, relatively easy to build and safe

lessons learned

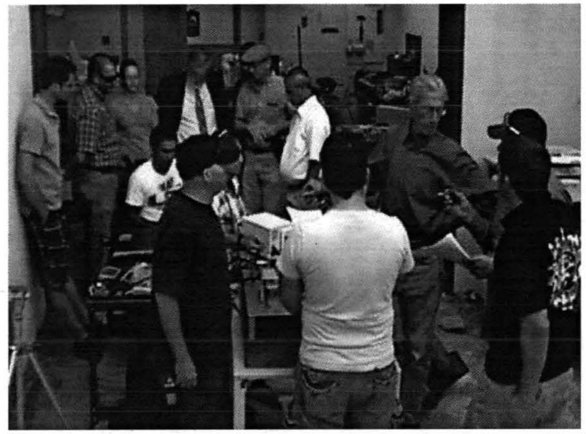
what didn't work; possible improvements

- more effort needed in working with students to select a project that requires integration of design effort in the end part of the process, e.g., marketing
- better instructions needed in how to keep student activity journals, along with good examples
- provide a convenient mechanism so that NASA experts can help evaluate students' presentations and papers
- students seemed quite unaware of the space program and its significance

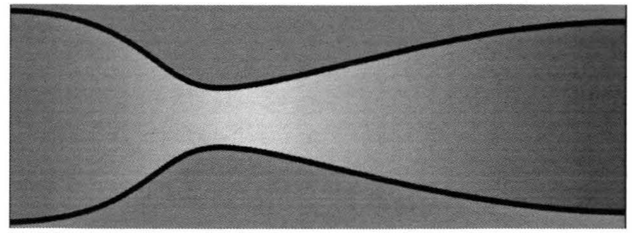
Part 2 – continued use

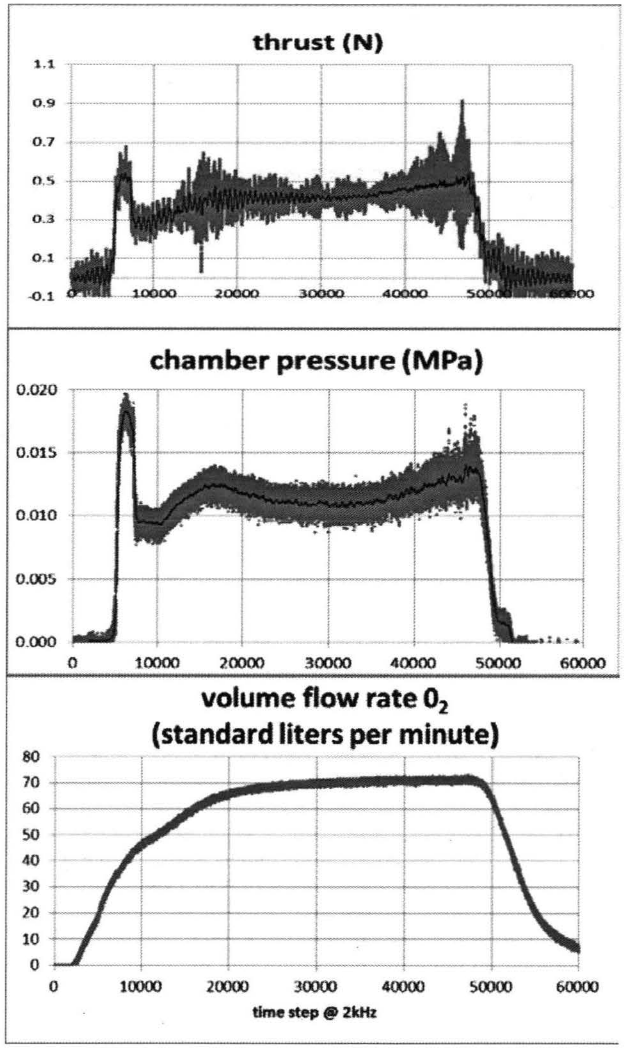


- nozzle design & testing
- fuel grain design
- efficient data analysis
- thrust stand re-design
- daq and control re-design
- increase portability
- temperature measurement
- remote operation (off the grid)
- many others



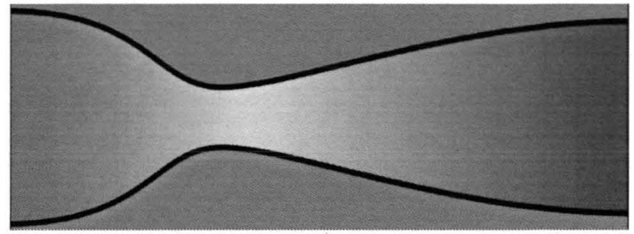
preliminary analysis

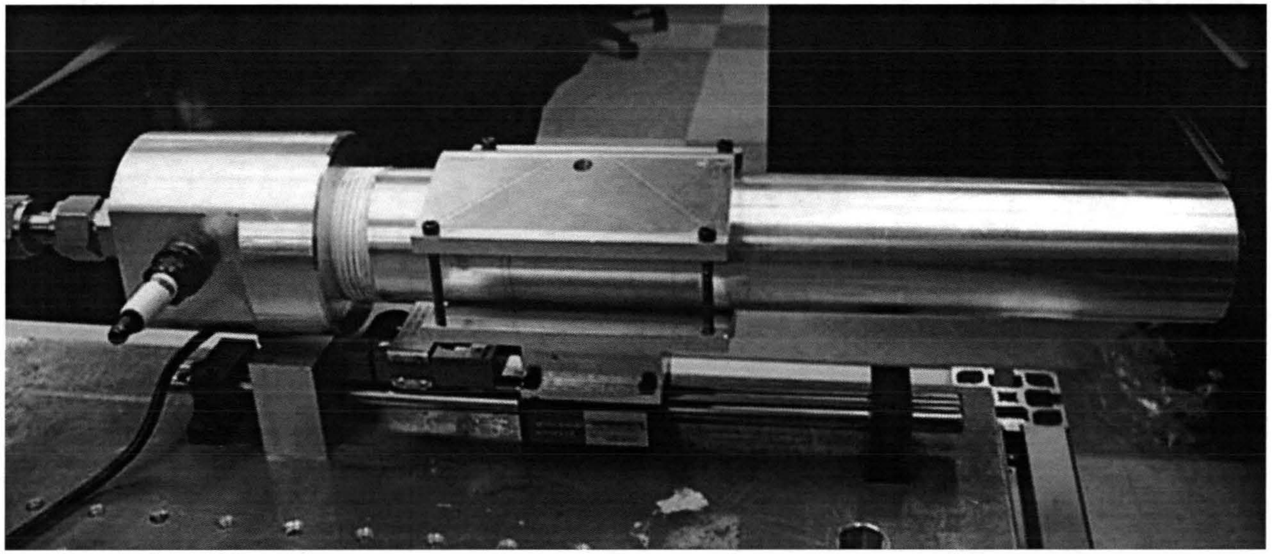


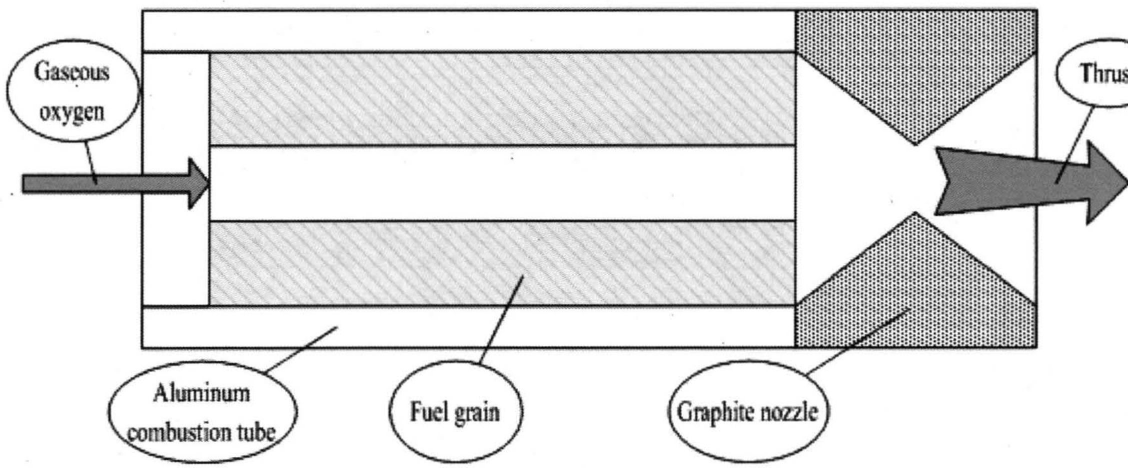


9.22	= total impulse (N-s) - platform load sensor
30.00	= duration of test (s)
0.31	= avg thrust - platform load sensor (N)
26.14	= total standard liters of oxygen (l)
1.17	= moles of oxygen
37.35	= mass of oxygen used (g)
10.71	= mass of acrylic burned (g)
0.25	= mass of teflon burned (g) - estimated
0.0483	= total mass ejected (kg)
0.00161	= average mass ejection rate (kg/s)
191	equivalent velocity (m/s) = total impulse/mass burned
19.4	= specific impulse (s)

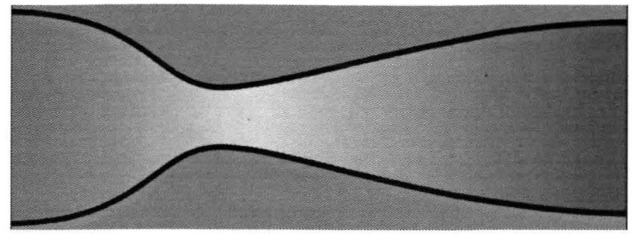
Anthony Marchase's Hybrid Rocket (Rowan)



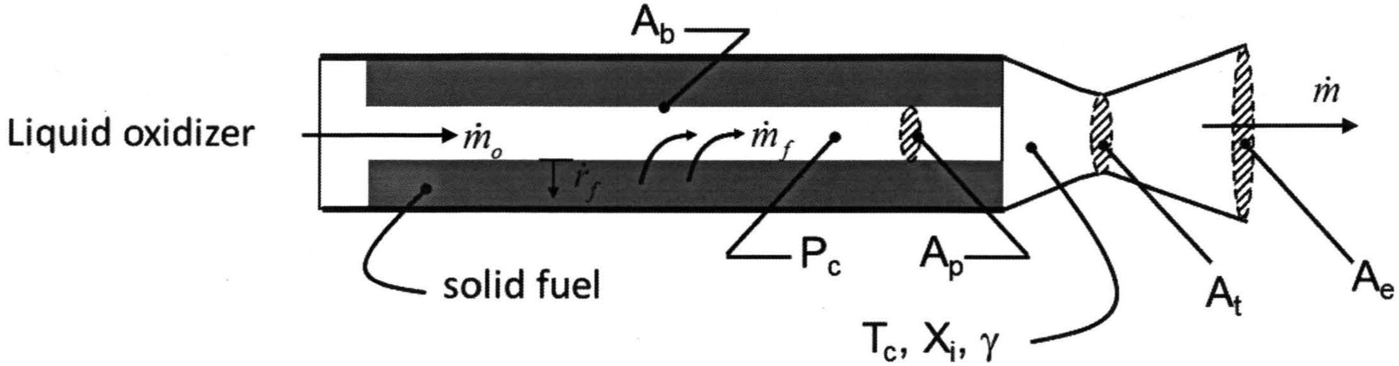




Hybrid Rocket Motor Design Project (credit Anthony Marchase)



Theoretical Model: This *is* Rocket Science



Fuel Regression Rate

$$\dot{r}_f(t) = a\left(\frac{\dot{m}_o}{A_p(t)}\right)^n$$

Fuel Mass Flow Rate

$$\dot{m}_f(t) = \rho_f A_b(t) a\left(\frac{\dot{m}_o}{A_p(t)}\right)^n$$

Chamber Pressure

$$P_c(t) = \frac{C^*}{A_t}\left\{\dot{m}_o + \rho_f A_b(t) a\left(\frac{\dot{m}_o}{A_p(t)}\right)^n\right\}$$

Thrust Coefficient

$$C_F = \sqrt{\gamma}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}\sqrt{\frac{2\gamma}{\gamma-1}\left(1-\left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right)} + \left(\frac{P_e}{P_c} - \frac{P_\infty}{P_c}\right)\frac{A_e}{A_t}$$

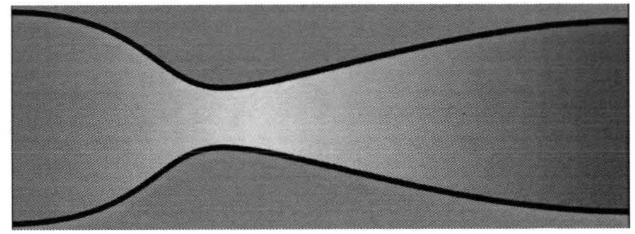
Thrust

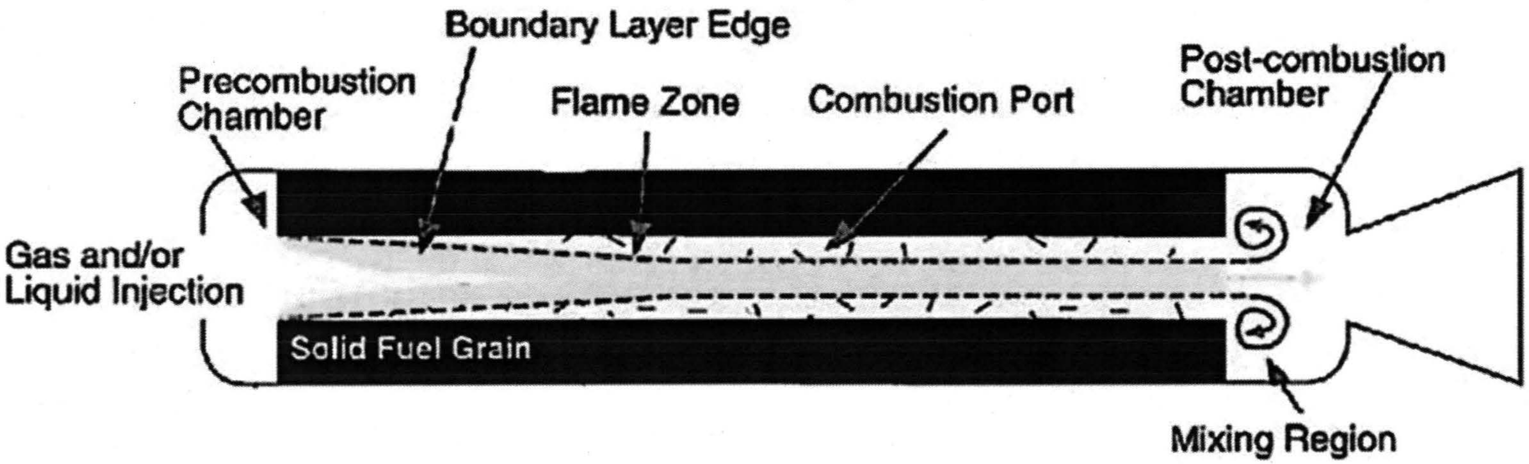
$$F = \dot{m} C^* C_F$$

Specific Impulse

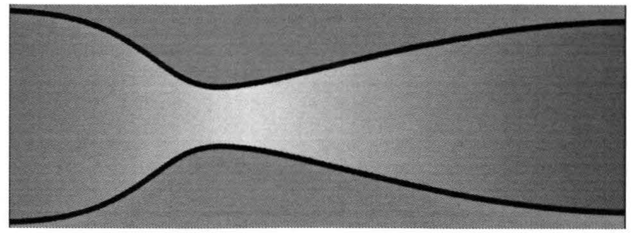
$$I_{SP} = \frac{\int F dt}{g_o \int \dot{m} dt} = \frac{C^* C_F}{g_o}$$

CFD regression rate analysis NASA fuel burn





Abstracted from American Institute of Aeronautics and Astronautics, Inc. (2007). *Fundamentals of hybrid rocket combustion and propulsion* (Vol. 218). (F. K. Lu, Ed.) Reston, Virginia: American Institute of Aeronautics and Astronautics.

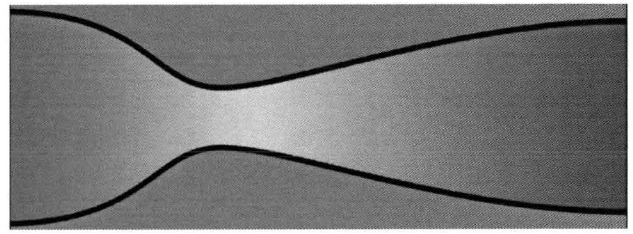


many thanks to

- Dr. Anthony Marchase (now at Co. State)
- Dr. Bill St. Cyr, retired,
- Phillip Hebert and Bryon Maynard,
- Dr. Fernando Figueroa, *all of* Stennis Space Center
- Dr. Pat Hynes, Director of NM Spacegrant and of the International Symposium for Personal and Commercial Spaceflight (ISPCS) http://www.ispcs.com/

and to numerous others

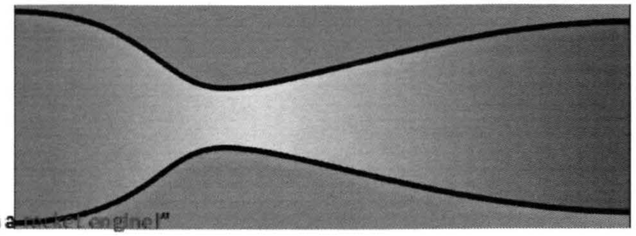
appendices



1. rudimentary cleaning procedure for O2 service
2. assembly procedure
3. safety check list
4. test procedure
5. commercially available product(s)
6. rocket working drawings
7. electrical diagrams
8. complete parts list

http://aggieconnection.org/Hybrid%20Rocket/hybrid_rocket.html

commercially available product



Hybrid Rocket Motor Desktop System

"Bringing Science, Technology, Engineering & Mathematics into the classroom on a rocket engine!"

Features:

- Actual firing of small rocket engine catches the attention and imagination of students, with digital readout and lighted display
- Users' Manual outlines exploration of STEM principles and experiments with the System, for example -
  - Uses a variety of fuels to demonstrate Science of chemistry and physics
  - Demonstrates the principles of hybrid rocket propulsion Technology from a classroom desktop
  - Comes with re-usable combustion chamber, to allow Engineering of additional fuels (according to directions)
  - Motor pressures recorded, to demonstrate how Mathematics can be used to calculate thrust levels
- Motor can be manually throttled or run a pre-programmed thrust profile, with throttle levels recorded for post-firing analysis
- High quality construction, parts and materials to maintain durable operations and appearance
- Potential for nozzle, injector and oxidizer to be changed, to use the instrument as a propulsion research tool
- Oxidizer refill kit is available for purchase, to demonstrate realistic pre-launch procedures

Designed for Safety*:

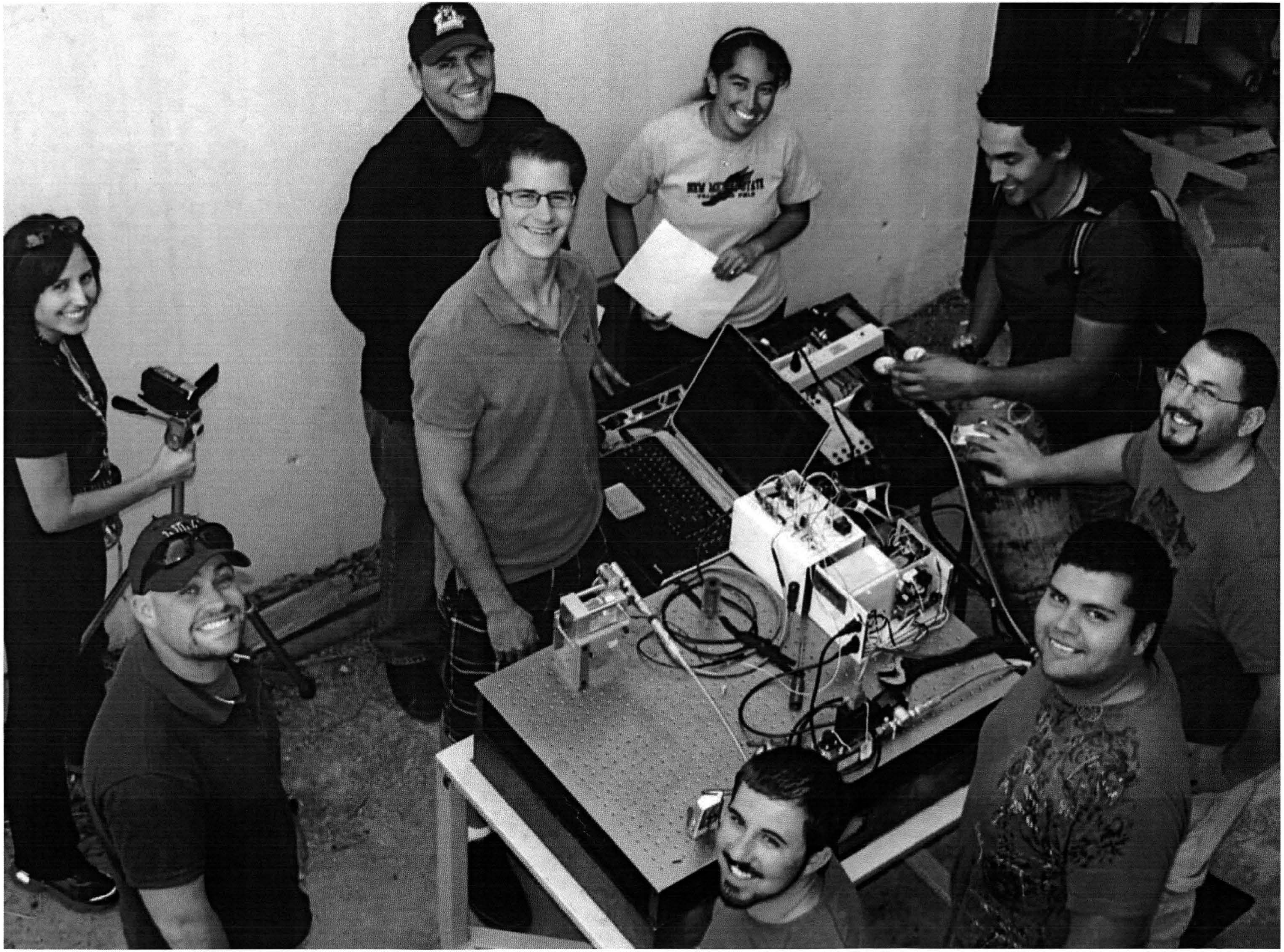
- Users' Manual outlines step-by-step safe operational procedures
- Automatic shut-off if safe operating pressures or temperatures exceeded
- Level and stationary condition required for operation
- Safety Screen must be in position for operation
- All pressure containment built to high factors of safety
- Separation of fuel and oxidizer minimizes safety concerns

Space Education Group stands behind its work:

- Manual fully describes safe and educational operation of the instrument
- Technical assistance is available via email or telephone
- On-site training and demonstration is available
- Comes with 10 fuel grains (4 types), and all components for operations**
- Warranted for one year or 10 rocket firings
- Additional and replacement fuel grains and other parts are available online

*The use of any flammable material, even a bunson burner, in a classroom comes with natural risks and dangers. Safety procedures outlined in the users' manual should be followed at all times.

** The supplied Oxygen bottle comes empty for legal shipment, and must be filled onsite or by an authorized gas dealer, such as those listed in the Manual.



Rudimentary Cleaning Procedure

Using this procedure, components can be cleaned to a visibly clean level. Cleaning can occur in a shop or a cruder environment if necessary. Obviously, the cleaner and more controlled the environment is, the better.

Several instructions or options are recommended during each step. Again, the more of these instructions and options that can be included in the cleaning process, the better.

Equipment:

Water:

Hot DI water, with a high pressure wand or nozzle.
If DI water is not available, use the cleanest available water supply.

Note: In all cases, warmer and cleaner water is better. If gloves can be worn to enable the water temperature to be higher, that is a favorable practice. Warm or hot water cuts grease and dissolves oil deposits far better than cool or cold water.

Pans:

Metal pans to contain cleaning solutions and rinse water. If metal pans are not available, plastic pans may be used.

Brushes:

Clean brushes in a variety of sizes and shapes to fit small crevices and reach all ends (e.g. spiral brush, end brush, bottle brushes, tooth-brush style brush), nonmetallic scouring pads.

Warning: Ensure that the brushes will not damage the hardware to be cleaned.

Warning: Do not use metallic scouring pads because they shed particles that can either rust or become imbedded in softer materials, or both.

Note: Brush or tool extensions can be fabricated, if necessary, to enable physical scrubbing of parts that are otherwise inaccessible.

Soap:

Soap with no moisturizers or scents added (e.g. Simple Green). If unavailable, use dish soap.

Gloves:

Nylon gloves that tend not to shed particulate. If non-shedding gloves are not available, use rubber gloves.

Rags:

Lint free cloth or paper wipes (e.g. Kimwipes), cotton cloth

Inspection Tools:

Magnifying glass, flashlight, otoscope (can be used for looking inside vessels and components), fluorescent lamp with magnifying glass, bright light source

Work surface and washing station:

Work surface and washing station that are located near one another

Metal surface that can be wiped clean or vsually clean plastic or paper sheet to cover work surface

Note: The work surface will be used to locate items that must be kept clean during the process such as clean brushes, wipes, bags, and gloves as well as provide a location that clean items can be located while preparing for bagging after the cleaning process is complete. Finally, the work surface will be used for disassembly and re-assembly of components.

The **general procedure** is as follows:

1. Prepare workplace
2. Disassemble
3. Pre-clean
4. Wash
5. Rinse
6. Inspect
7. Dry
8. Re-assemble
9. Package
10. Label

Prepare Workplace

Chose a work area that is somewhat controlled to avoid open access and to minimize contamination. Get all supplies and tools together before beginning the cleaning process to avoid delays once the cleaning process is underway.

Wipe down the metal work surface or place a clean plastic sheet or clean paper on the work surface.

- Ensure that the work surface remains visually clean during the disassemble and cleaning process.
- If necessary, wipe down the work surface to ensure that contamination from one item does not get transferred to other items.

Set up a series of wash/rinse pans

- Wash pans should progress from less to more clean.
- For example, the first pan might contain hot, soapy water for pre-cleaning and soaking dirtier items. The second pan might contain hot, soapy water for scrubbing cleaner items. The third pan might be for initial rinsing, and the fourth pan might contain clean, hot water for final rinsing.
- Change out the water in each pan as required when it becomes dirty.

Disassemble

Completely disassemble the component so that all crevices and internal surfaces are as accessible as possible.

Note: Each part must be cleaned separately, in a disassembled configuration. If they are not, the effectiveness of the cleaning procedure will be significantly reduced. Parts that are not removed provide crevices and cracks that will retain contaminants and it will not be possible to clean the adjoining surfaces of the parts.

Pre-clean

Remove excessive contamination.

- Wipe the component.
- Discarding the soiled wipes.
- Continue this process until as much visible contamination is removed as possible.

Wash

Soak item in hot (the hotter, the better), soapy water as needed to loosen contaminant from surfaces.

- If item is a tank or a bottle, fill it with soapy water until it is overflowing, then let it soak.

Scrub/agitate the part thoroughly.

- Use brushes, wetted Kim Wipes, or cotton cloth.
- Pay special attention to threads, crevices, and hidden surfaces that, because of their configuration, can trap contaminants.
- If internal surfaces cannot be scrubbed mechanically then spray the inaccessible areas. If scrubbing or spraying are not possible, fill the item with hot, soapy water, plug the holes and shake it vigorously.

  Note: Ensure that many suds are formed during the washing process, if there are few suds then add more water and soap. If suds don't form, it indicates that the all the oil contamination is not captured by the surfactant.

- Change the wash water, add soap, and repeat the washing process twice for a total of three washes.

  Note: This procedure amounts to very rigorous dish-washing with very careful attention given to detail and precision. The hotter and soapier the water the better. The repetitions ensure that the surface is thoroughly cleaned and that layered contamination is wetted, agitated, and removed.

Rinse

Rinse item thoroughly to remove soap and contaminant.

- Dunk and spray item with clean, hot water as needed to remove all visible residues.
- If item is a bottle then fill, shake, and empty the water until no suds are left and the water coming out is as clear as water going in.

    Note: Nylon gloves should be rinsed often to remove contaminants and particles obtained by touching contaminated parts. If a particle can be transferred to a cleaned part by physical contact, it is very likely that it can be rinsed off. Rinse it off prior to touching the parts.

- Inspect rinse water.
    - Catch the last rinse water in clear a container.
    - Look for particles or grease in the water using a magnifying glass and by shinning a bright white light through water
    - If no particles are present or grease is observed on the surface (as a colorful sheen) and the water is as clear as it was from the source, move on to drying, if not repeat the **Wash** and **Rinse** steps.

Note: When washing carbon steel components, like the oxygen bottles, perform the final rinse with cold water and then dry immediately. The combined effects of cooling the carbon steel surface and drying it quickly will inhibit as much as possible the formation of rust.

Dry

Blow dry.

- Use oil-free, filtered GN2 or air if available.
- If filtered gasses are not available, use filtered compressed or canned air.

    Note: It is preferable to dry parts quickly, removing all water droplets, to avoid deposits of water-borne contaminants (water spots).

Air dry.

- Set aside in a clean, isolated area to air dry.

Wipe dry.

- If water droplets remain, they can be carefully removed using a clean, folded Kim Wipe

Inspect

Inspect item to verify cleanliness.

- Visually inspect, using magnification if available, all surfaces using the most intense light available.
- Take care to inspect small crevasses, threads, and holes.
- If any discoloration, water deposits, soap residue, or particulate are observed, remove it. If necessary, repeat the **Wash** and **Rinse** steps.

Note: if there is a significant delay between the cleaning and reassembly steps, then bag the parts to avoid contamination during the delay.

Reassemble

Reassemble the component.

- Prepare a clean, dry work surface on which to reassemble the component
- Don clean, dry nylon gloves.
- Set the cleaned, dried parts in a protected location to avoid contamination prior to and during reassembly process.
- Assemble the component.
- If gloves become soiled with lubricant or any other substance, change the gloves prior to touching the clean parts.

Package

Bag the item

- It is preferable to double bag the component with an in inner bag of Nylon or Teflon and an outer bag of Polyethylene
  - Heat seal the bags
- If Nylon or Teflon bags are not available, seal the item in a Polyethylene bag or a Zip-Lock bag.

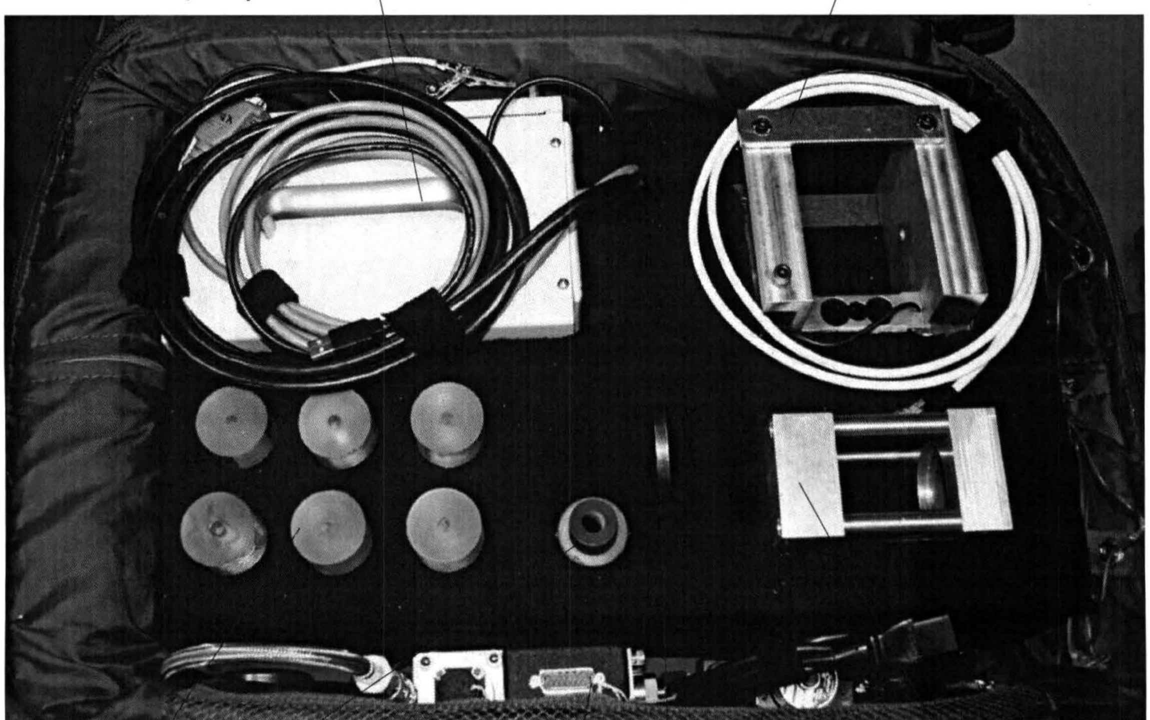
Hybrid Rocket Assembly Instructions - DRAFT

Required Equipment (supplied by host)

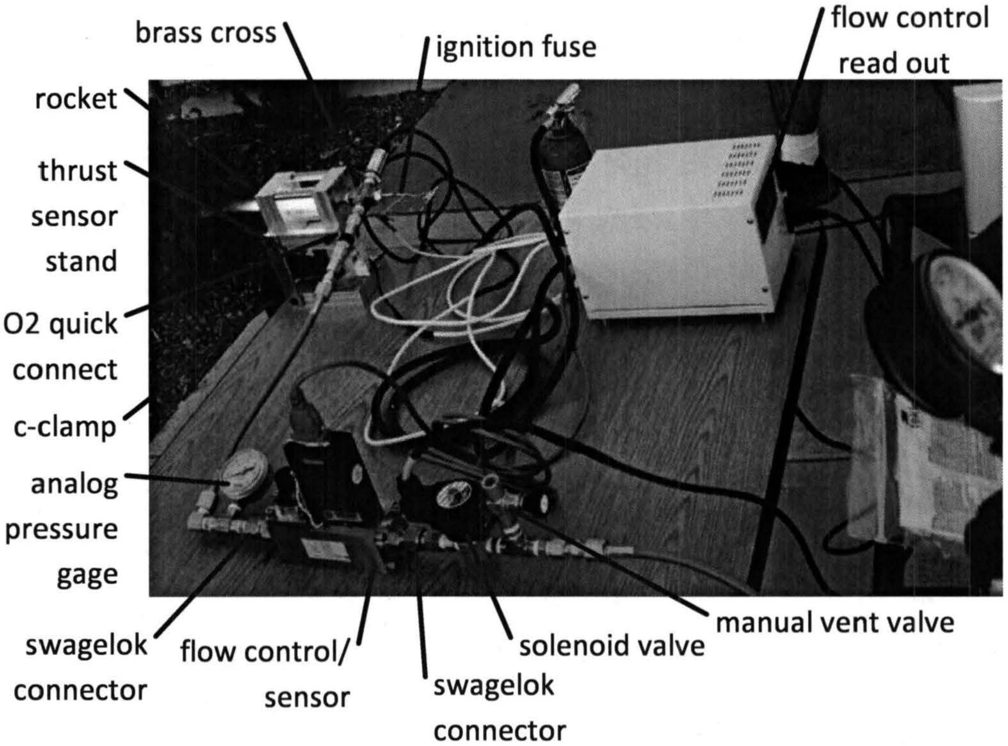
1. Gaseous oxygen tank and regulator.
2. Standard 120V ac power source and extension cord as needed.
3. Reasonably sturdy table.
4. Fire Extinguisher.

Assembly Procedure

1. Remove components from case.
   a. From the zippered compartments, remove the O2 supply plumbing, which connects the flexible line to a ¼"NPT brass cross, and to the pressure sensor. Also remove the tools.



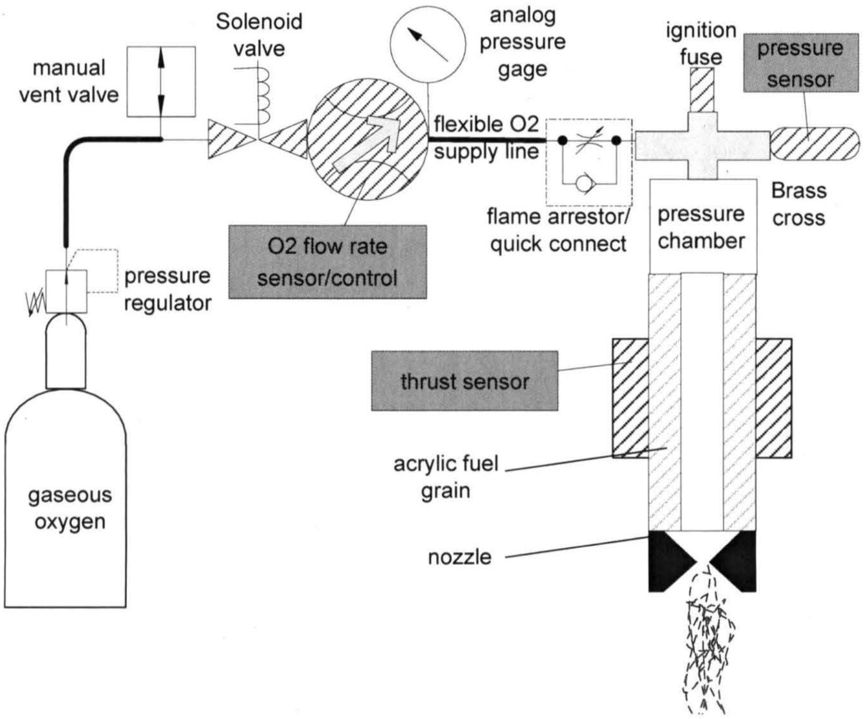
   b. Open the case, shown above, and remove the thrust stand, nozzle, injector plate, and rocket. Remove the control/daq module last. Position the components to be assembled as seen in the figure on page 2.



2. Assemble the rocket
   a. Remove the downstream plate from the struts
   b. Insert injector plate into the upstream plate, with the countersink towards the fuel grain
   c. Insert fuel grain into the countersink of the injector plate
   d. Place the Teflon washer between the fuel grain and the nozzle
   e. Place the downstream plate over the nozzle and secure to the struts using the supplied Allen screws
3. Thread the fuse wire into the fuel port and screw the nipple into the brass cross.
4. Connect 'quick-connect' oxygen line from the flow controller to the brass cross assembly
5. Secure rocket assembly to the thrust stand by means of Allen screws (finger tight)
6. Tighten the two stainless steel swagelok joints upstream and downstream of the flow controller/sensor
7. Secure thrust stand the table by means of a C-clamp
8. Connect the wiring: strain gauge, pressure transducer, flow controller, power cable, 'dead man' switch, solenoid valve, and USB cable
9. Attach the supplied regulator to oxygen tank
10. Connect flexible oxygen line from O2 regulator to the flow controller
11. Tighten swivel joints on the upstream and downstream side of the flow controller

12. Place the fire extinguisher at a ready location

For reference, the figure below diagrams the O2 handling system.



Prepare for firing by following the Test Procedure Document.

Disassembly Procedure

1. Turn off main oxygen supply
2. Vent excess oxygen using the manual vent valve
3. Allow rocket to cool
4. Wearing gloves,
   a. disconnect the quick connect line from the ignition system
   b. remove rocket assembly from the test stand
   c. remove ignition assembly from the upstream plate
5. Disassemble the rocket assembly
   a. Remove diffuser, fuel, Teflon washer, and nozzle
   b. Attach the bottom plate to the struts and top plate to be stored
6. Disconnect all wires and roll them up
7. Disconnect oxygen line upstream of the flow controller
8. Loosen the stainless steel swivel joint downstream of the flow controller for storage
9. Replace the spent ignition fuse with a new one
10. Place all components into the case. The controller/daq module goes in first. Position it with the feet toward the side (or bottom) of the case and the permanently attached cables toward the dedicated cutout.

Pre-Operation Safety Checklist

Ensure all items on this checklist are complete during or after the assembly procedure prior to operating the Portable Hybrid Rocket.

Required Item	Complete?
Fire extinguisher or equivalent Fire Suppression system present	
Test environment is well-ventilated and free of flammable materials	
All test participants wearing eye and ear protection	
Rocket engine fully assembled, all screws tightened	
Test stand firmly attached to flat, level surface	
Manual pressure relief (vent) valve is in the CLOSED position	
Oxygen hoses fully connected and verified free from leaks	
Rocket engine securely mounted on test stand	
All electrical connections are secure, no frayed or exposed wiring	
Emergency shutoff switch tested and verified to be functional	
All observers of the rocket are on the inlet side of the assembly (no observers in front of the exhaust plane)	

Hybrid Rocket Test Procedure – DRAFT revision 2

1. Five tasks are required. We have organized the test team this way:
   - Fire Watch
   - Deadman Switch Operator
   - Time Clock Operator
   - Data Recorder
   - LabVIEW Operator
2. Verify the Pre-Operation Safety Checklist is complete.
3. Conduct pre-test briefing: eye, ear protection; establish a clear area downstream of nozzle.
4. All test personnel record his/her name and on the Test Data Sheet.
5. **LabVIEW Operator,** first reset the O2 flow controller. Press 'mode' then ensure the daq system is operating. The three signals are load cell, pressure transducer, and flow rate.
6. **Data Recorder,** record the following on the Test Data Sheet:
   - Test number and current date and time
   - Test Location
   - Initial fuel grain weight
   - If applicable, model number of nozzle. If not, write **N/A**.
7. Rotate the O2 regulator control valve ccw in order to lower output pressure. Open the main O2 valve slowly. Rotate the control valve cw to approximately 40 psi.

The test may now begin

8. **Shutoff Switch Operator,** pull the trigger switch to open the normally-closed O2 solenoid supply valve.
9. **LabVIEW Operator,** perform the following steps:

   9.1. Using the instrumentation software, set the oxygen flow controller to the desired flow rate and allow the flow to stabilize.

   9.2. Record the following on the Test Data Sheet:
   - Data acquisition rate in samples/sec

- Stabilized oxygen flow rate value

9.3. Attach power supply to ignition system.

~~9.3.~~9.4. Verify the established clear area.

~~9.4.~~9.5. Begin data acquisition and verbally countdown to rocket ignition.

10. At the end of the countdown, **LabVIEW Operator,** ignite the rocket while the **Time Clock Operator,** begins the timer.
11. If an unforeseen event occurs, the **Shutoff Switch Operator** shall release the shutoff switch to terminate the test.
12. **Time Clock Operator,** provide the Shutoff Switch Operator with a verbal countdown or visual indication when the test time has expired.
13. **Shutoff Switch Operator,** when given notification to end the test, perform the following steps:

    13.1. Release the shutoff switch trigger to cut off the flow of oxygen to the rocket engine.

    13.2. Fully close the main supply valve on the O2 tank.

    13.3. Briefly open the pressure release valve to vent any residual O2 trapped in the system between the O2 regulator and the solenoid valve.

14. **LabVIEW Operator,** end data acquisition and save the file.
15. **Data Recorder,** record the following on the Test Data Sheet:
    - Duration of test, in seconds
    - Filename of current data set
    - Any additional comments or observations about the test
16. Once all test operations are complete and the hardware has cooled sufficiently (to the touch – roughly 20 minutes), disassemble the rocket, instrumentation, and oxygen hoses.
17. **Data Recorder,** if a scale is available, record the final fuel grain weight on the Test Data Sheet. If not, segregate the fuel grain for future analysis.
18. Remove the oxygen tank regulator and screw the valve stem cap onto the oxygen tank.
19. Place all hardware carefully into the foam inserts in the carrying case as outlined in the Assembly/Disassembly Procedure document.

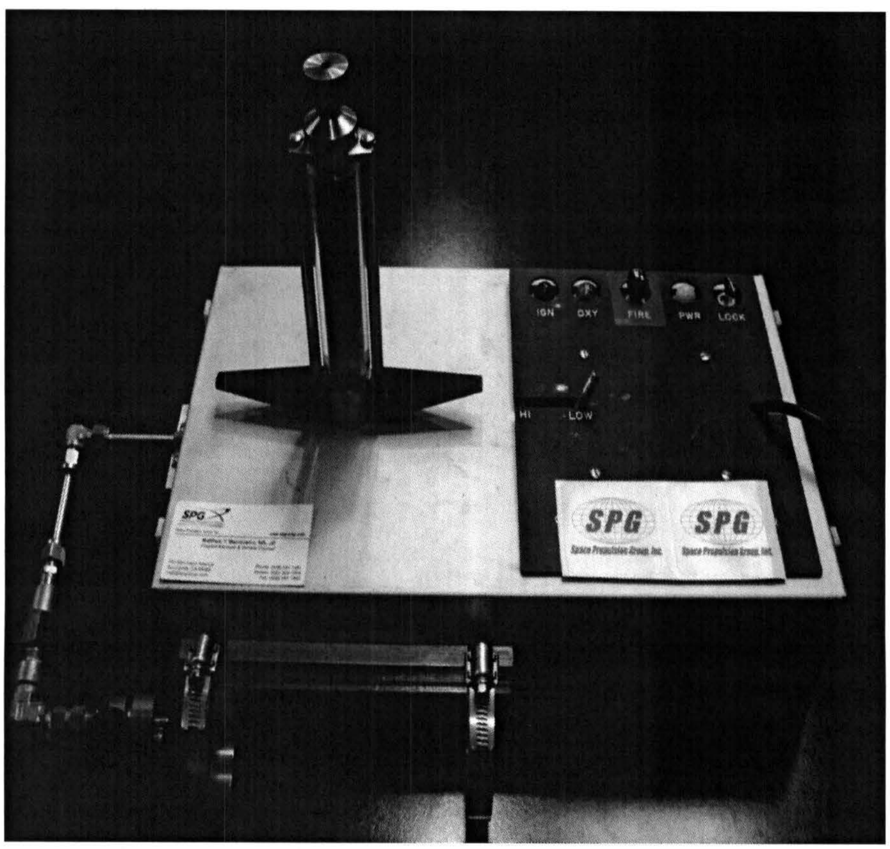
Desktop Hybrid

General Specifications of the System:

- Gaseous oxidizer
- Multiple fuels: Plastics, clear plastics (i.e PMMA), paraffin, wood ....
- Modular injector design
- Throttling
- Stainless steel nozzle
- Fully electronic ignition/controls
- Chamber pressure measured
- Flow rate and chamber pressure can be controlled

Other Features

- Perfect for educational purposes
- Can be fired in doors
- Suitable for simple research projects
- Comes with the user's manual and basic hybrid rocket design manual

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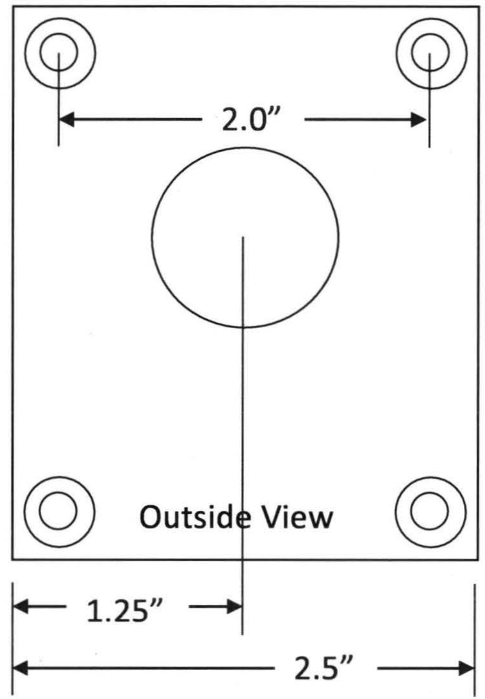
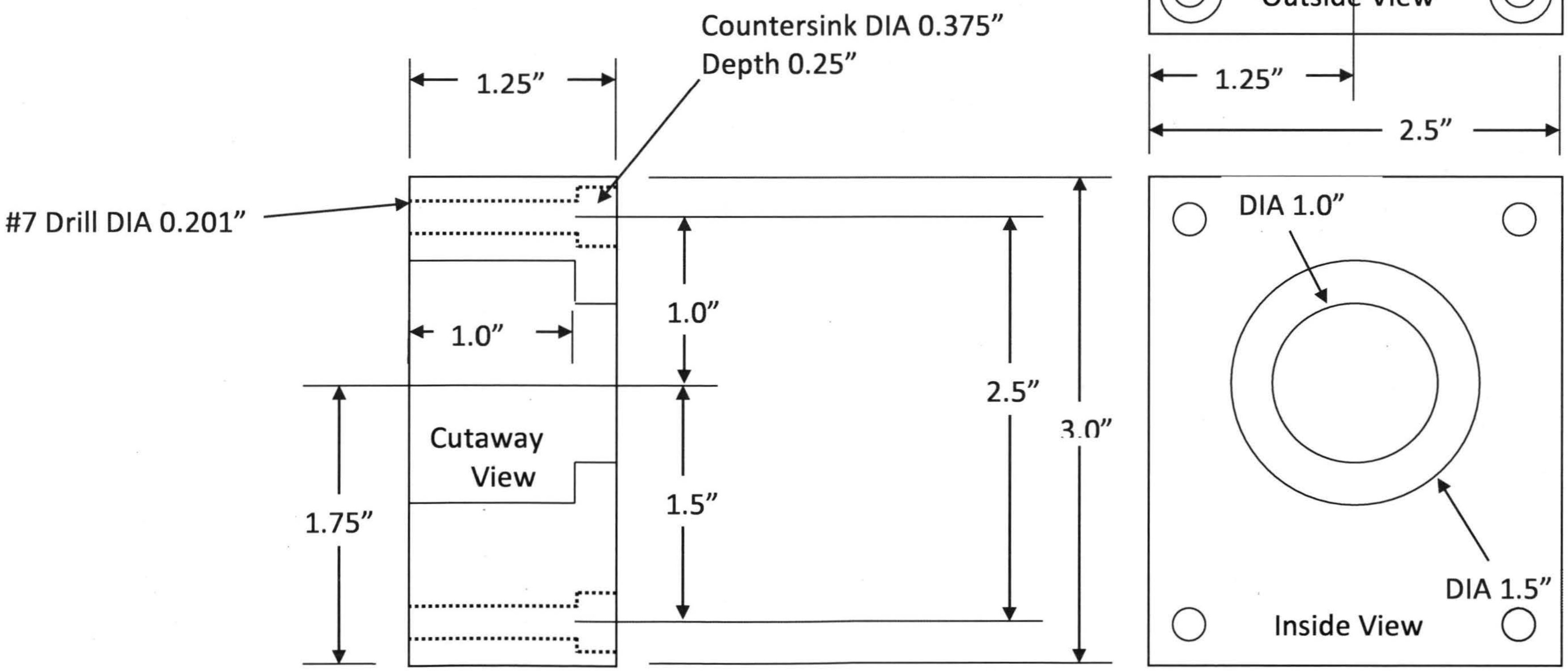
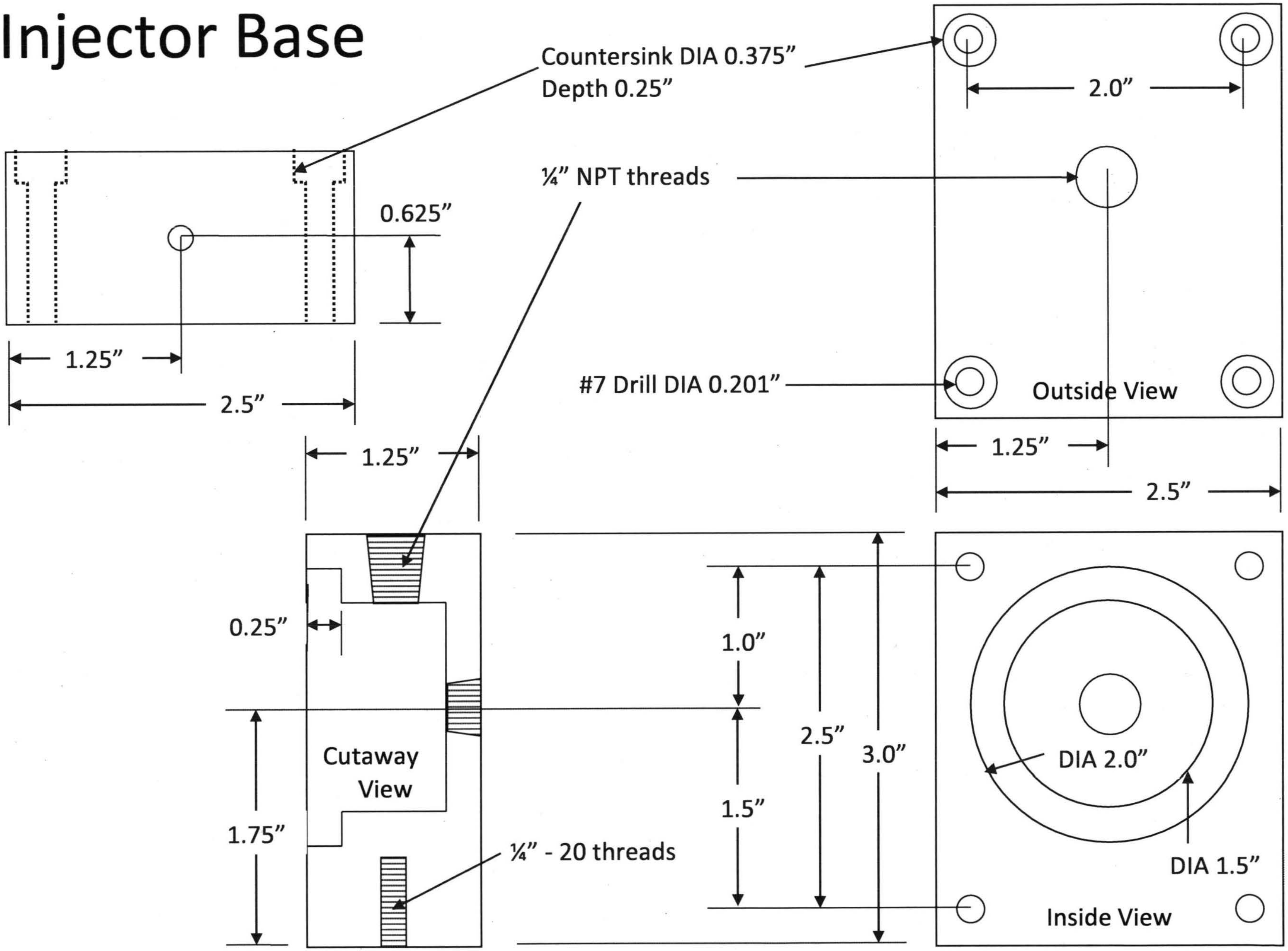
Nozzle Base
Courtesy Stennis Space Center

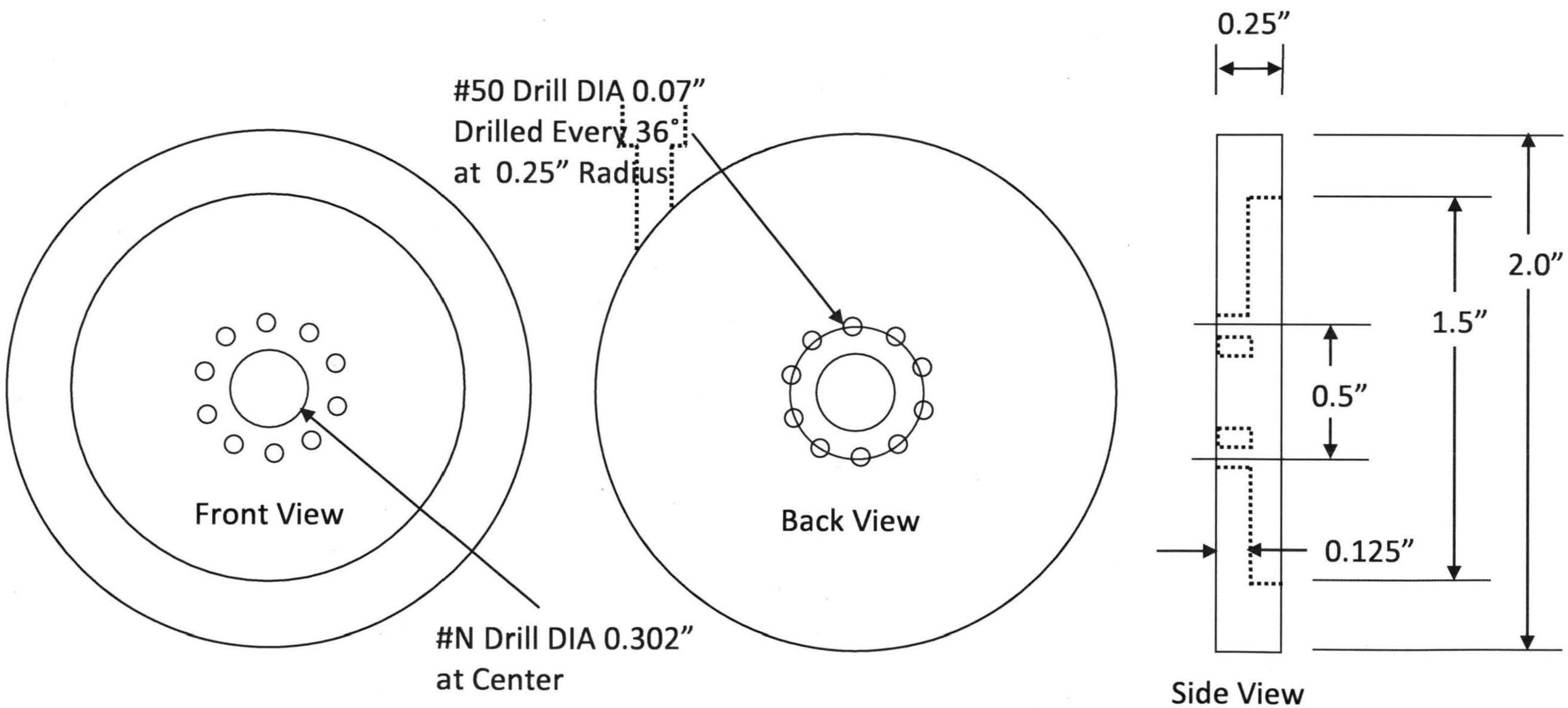




Injector Base

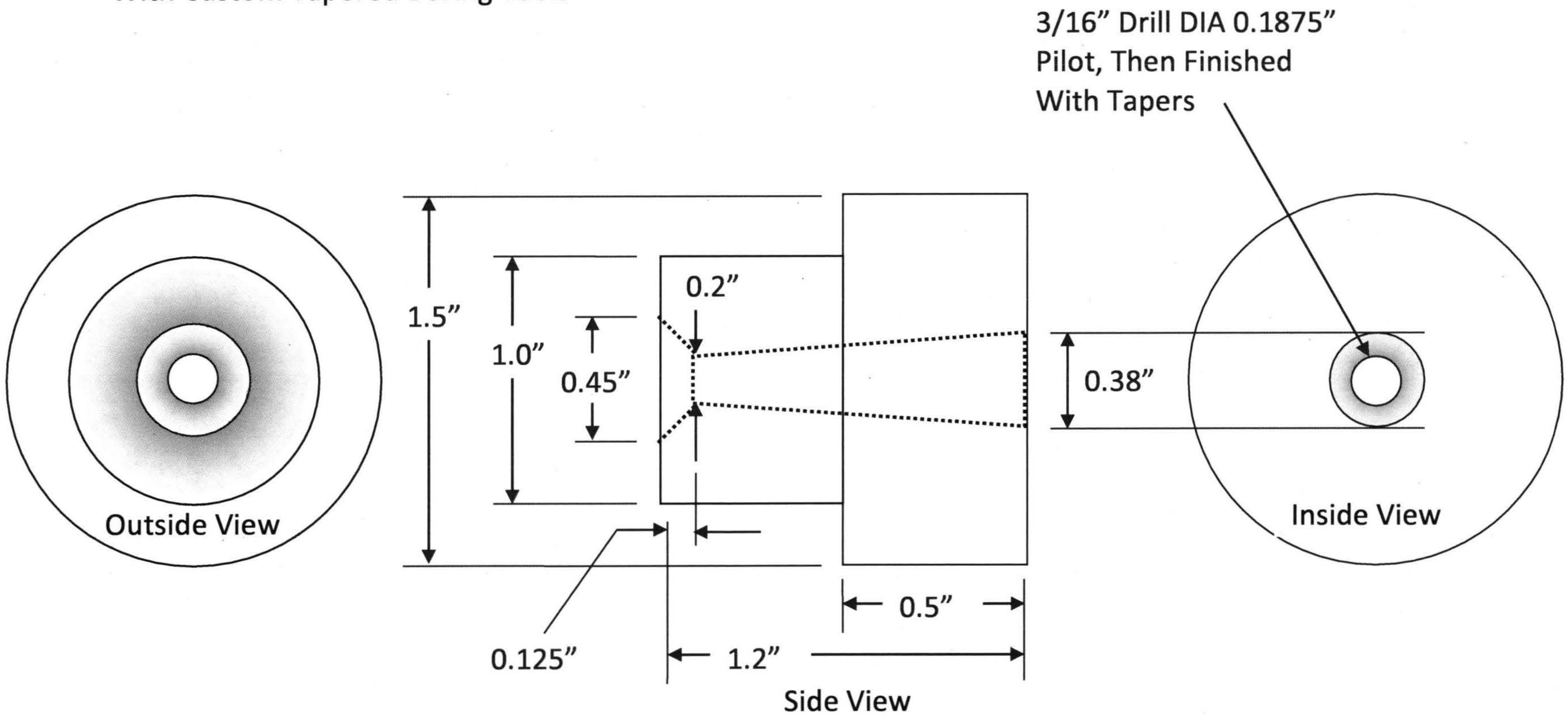


Injector Plate



Nozzle

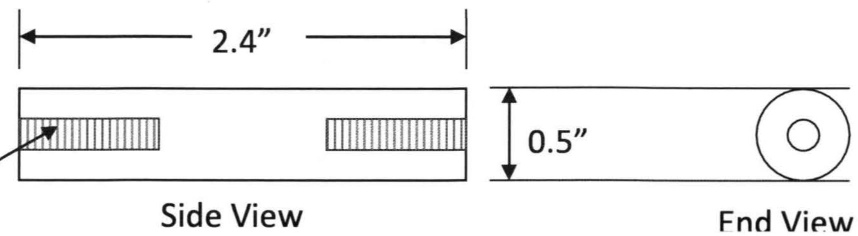
Solid Graphite - Machined and Drilled
With Custom Tapered Boring Tools



Standoffs

Make four (4) Stainless Standoffs

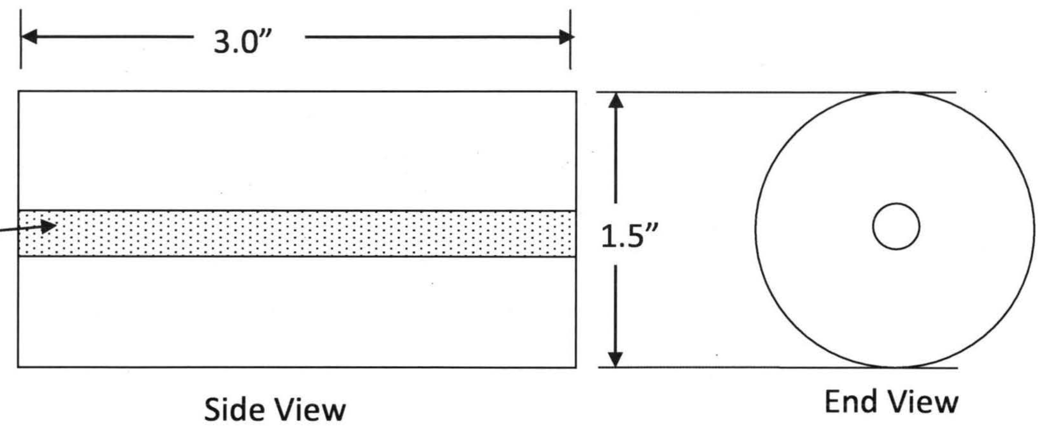
#10 - 32 threads,
Depth 0.75" (min)



Fuel Grain

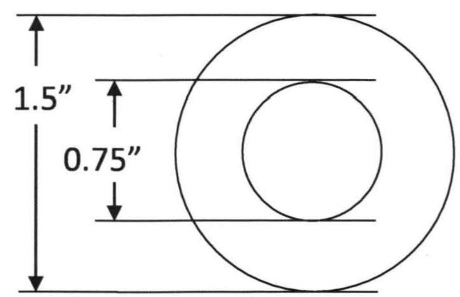
Use Only Cast Acrylic Rod Stock

1/4" Drill DIA 0.25"
At Center

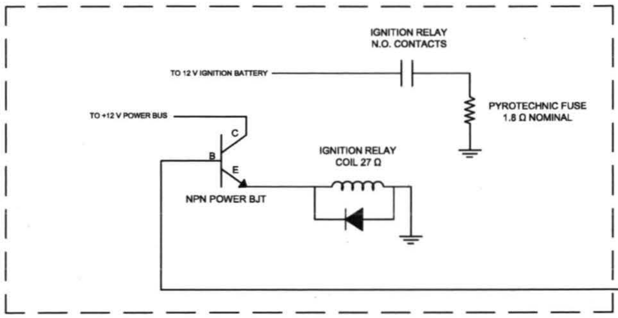


Gaskets

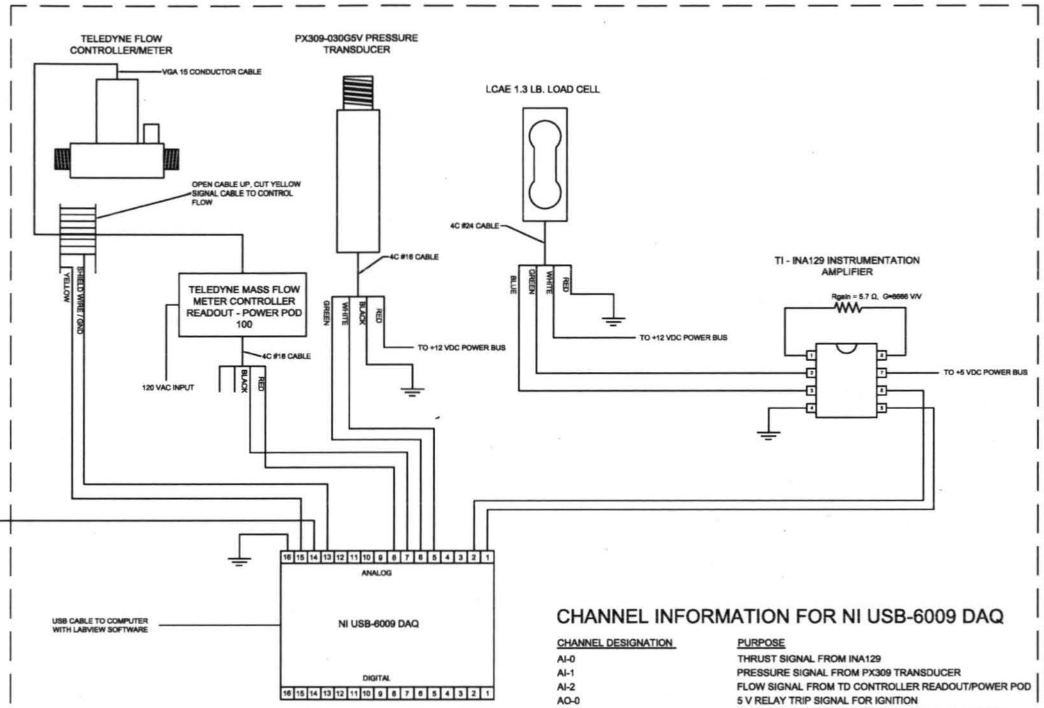
Make two (2) Teflon Gaskets



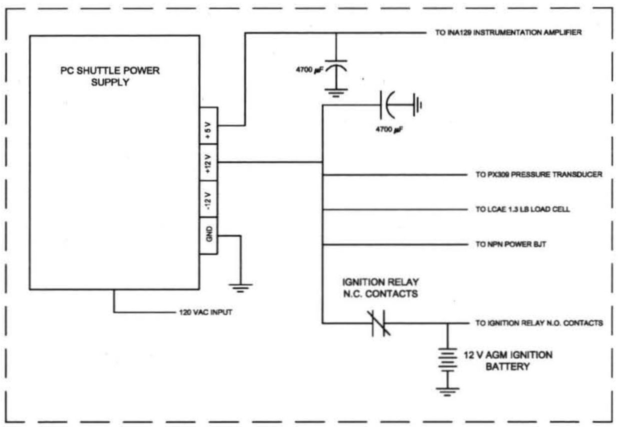
ENGINE IGNITION SYSTEM



DAQ ELECTRONICS SYSTEM



POWER SYSTEM



CHANNEL INFORMATION FOR NI USB-6009 DAQ

CHANNEL DESIGNATION	PURPOSE
AI-0	THRUST SIGNAL FROM INA129
AI-1	PRESSURE SIGNAL FROM PX309 TRANSDUCER
AI-2	FLOW SIGNAL FROM TD CONTROLLER READOUT/POWER POD
AO-0	5 V RELAY TRIP SIGNAL FOR IGNITION
AO-1	0-5 V SIGNAL FOR FLOW CONTROL, 0V OFF, 5V FULLY ON

IGNITION RELAY SPECIFICATIONS

MANUFACTURER:	RAYEX ELECTRONICS
MODEL:	L90-5W
INPUT FREQUENCY RANGE:	50-60 Hz
COIL RATING:	27 Ω - 5 VDC
CONTACT RATING:	20 AMP @ 277 VAC RMS 20 AMP @ 30 VDC

PC SHUTTLE POWER SUPPLY SPECIFICATIONS

MANUFACTURER:	INTEGRATED POWER DESIGN INC.
MODEL NO.	SRW-45-3001
INPUT VOLTAGE:	85-264 VAC
INPUT FREQUENCY RANGE:	47-63 Hz
MAX POWER OUTPUT:	45 WATTS
OUTPUT VOLTAGES:	+5 VDC @ 5 A +12 VDC @ 3 A -12 VDC @ .70 A

NPN POWER BJT SPECIFICATIONS

MANUFACTURER:	ST MICROELECTRONICS
MODEL:	TIP3055
POWER DISSIPATION:	75 WATTS
C - E VOLTAGE RATING:	60 V
C - B VOLTAGE RATING:	70 V
E - B VOLTAGE RATING:	5 V
COLLECTOR CURRENT RATING:	10 AMPS

12 V AGM IGNITION BATTERY SPECIFICATIONS

MANUFACTURER:	B & B BATTERY
MODEL:	BP5-12
NOMINAL VOLTAGE:	12 VOLTS
CAPACITY:	5 Ahr
MAX DISCHARGE CURRENT:	75 A (5 sec)
WEIGHT:	3.97 lbs.

ANALOG PIN ASSIGNMENTS FOR NI USB-6009 DAQ

PIN NUMBER	DESIGNATION
1	GND
2	AI-0
3	AI-4
4	GND
5	AI-1
6	AI-5
7	GND
8	AI-2
9	AI-6
10	GND
11	AI-3
12	AI-7
13	GND
14	AO-0
15	AO-1
16	GND

NM STATE

KLIPSCH SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

NOTES

GENERAL

LEGEND

— — SYSTEM BOUNDARY MARKER

——— WIRES

RESISTOR

RELAY COIL

☐ -PRELIMINARY
■ -APPROVAL
☐ -CONSTRUCTION
☐ -AS BUILT

DRAWING APPROVAL SIGNATURE

NMSU ELEC. ENGINEERING SUPERVISOR | NMSU ELEC. ENGINEERING MANAGER

NO.	DATE	REVISION	BY / CH
1	12/13/2011	CREATE PRELIMINARY DRAWING	KPD/KPD

ROCKET STAND CAPSTONE

CLASSROOM PROPULSION DEVICE
ELECTRICAL DESIGN MK. 6

NEW MEXICO STATE UNIVERSITY
DEPARTMENT OF ELECTRICAL ENGINEERING

DRAWN BY: K. DE HERRERA	DATE: 12/13/2011
CHK. BY: K. DE HERRERA	APP. ENG. M. MONTOYA
APP. SUPV. E. CONLEY	DRAWING NUMBER RSC-106 SHT 6 OF 6

Plumbing/Hardware Parts List

Item (In Downstream Order)	No.	Quantity	Unit Price
1/4" Straight Brass Regulator to Hose Coupler	1	1	$2.73
Female Flexible Pigtail	2	2	$33.33
1/4" MNPT to Compression Brass Coupler/Adapter	3	1	$3.04
1/4" MNPT Brass Connector	4	1	$1.92
1/4" FNPT Brass T-Fitting	5	1	$6.97
1/4" FNPT Brass Swagelok Valve	6	1	$7.48
1/4" MNPT Brass Connector	7	1	$1.92
Jefferson 1/4" FNPT Solenoid Valve	8	1	$101.95
1/4" MNPT Brass Connector	9	1	$1.92
Teledyne Hastings HFC-203 Flow Meter/Controller w/ Power Pack	10	1	$2,500.00
1/4" MNPT Brass Connector	11	1	$1.92
1/4" FNPT Brass T-Fitting	12	1	$6.97
10psi Analog Pressure Gauge	13	1	$8.83
1/4" MNPT Brass Connector	14	1	$1.92
1/4" FNPT to MStraight Brass 90 Degree Fitting	15	1	$1.57
Female Flexible Pigtail	16	1	$33.33
1/4 " Torch to Hose Quick Connect Set	17	1	$63.26
1/4" MNPT Brass Connector	18	1	$1.92
1/4" FNPT Brass Cross Fitting	19	1	$5.53
1/4" NPT Brass Barb Hose Adapter	20	1	$3.32
Aerotech First Fire Ignitor Jr. (Fuse 3 Pack)	21	1	$9.99
Omega Pressure Transducer PX309-030G5V	22	1	$225.00
1/4" MNPT Brass Connector	23	1	$1.92
3"x12"x1.5" 6061 Aluminum Billet (Engine Plates)	24	1	$39.29
36"X0.5"dia. 6061 Aluminum Round Stock (Engine Struts)	25	1	$7.52
12"x2"dia. General Purpose Steel Round Stock (Diffuser Plate)	26	1	$34.70
72"x1.5" Extruded Acrylic Round stock (Fuel Grain)	27	1	$55.43
6"x6"x1/16" PTFE Teflon Sheet (Interior O-Ring)	28	1	$17.25
12"x1.5"dia. Graphite Round Stock (Nozzle)	29	1	$78.47
5"x12"x1" 6061 Aluminum Billet (Test Stand Plates)	30	1	$43.87
Omega 1.5lb Single Point Load Cell	31	1	$136.00
6'x12"x0.25" 6061 Aluminum plate (Test Stand Arms)	32	1	$16.02
Remote Starter Switch ("Deadman" Switch)	33	1	$12.99
Travel Case	34	1	$69.99
Edge Foam	35	1	$26.75
Smart Foam Pad	36	1	$8.99
Miscellaneous	37	1	$50.00

Electronic Controls Parts List

Item	No.	Quantity	Unit Price
Electronics Case	38	1	$10.00
9V Rechargable Battery	39	2	$9.00
12V UPS Battery	40	1	$27.23
Digital Power Supply	41	2	$76.30

Method of Acquirement	Cost
Store Purchase	$2.73
Store Purchase	$66.66
Store Purchase	$3.04
Store Purchase	$1.92
Store Purchase	$6.97
Store Purchase	$7.48
Store Purchase	$1.92
Online Purchase	$101.95
Store Purchase	$1.92
Online Purchase	$2,500.00
Store Purchase	$1.92
Store Purchase	$6.97
Store Purchase	$8.83
Store Purchase	$1.92
Store Purchase	$1.57
Store Purchase	$33.33
Store Purchase	$63.26
Store Purchase	$1.92
Store Purchase	$5.53
Store Purchase	$3.32
Online Purchase	$9.99
Online Purchase	$225.00
Store Purchase	$1.92
Online Purchase	$39.29
Online Purchase	$7.52
Online Purchase	$34.70
Online Purchase	$55.43
Online Purchase	$17.25
Online Purchase	$78.47
Online Purchase	$43.87
Online Purchase	$136.00
Online Purchase	$16.02
Store Purchase	$12.99
Store Purchase	$69.99
Store Purchase	$26.75
Store Purchase	$8.99
Store/ Online	$50.00
Approx. Total	$3,654.61

Method of Acquirement	Cost
Store Purchase	$10.00
Store Purchase	$18.00
Store Purchase	$27.23
Online Purchase	$152.60

PCB Designs Boards	42	4	$45.00
Operational Amplifiers	43	10	$8.00
Rectifying Diodes	44	2	$2.50
Filtering Capacitors	45	1	$5.00
Voltage Regulators	46	4	$3.50
Calex Digital Converter	47	1	$124.00
250V 5A Relay	48	1	$10.00
TIP Power BJT	49	2	$3.49
National Instruments USB-6009 DAQ	50	1	$279.00
National Instruments LabVIEW Software	51	1	$3,195.62
CAT5e Cable (20')	52	1	$11.43
RJ45 Modular Connector (M/F 6 Pack)	53	3	$14.40
6 Port Telecom. Face Plate	54	1	$1.98
Face Plate Blank (10 Pack)	55	1	$2.99
USB Cable	56	2	$6.99
Miscellaneous	57	1	$50.00

Online Purchase	$180.00
Online Purchase	$80.00
Online Purchase	$5.00
Online Purchase	$5.00
Online Purchase	$14.00
Online Purchase	$124.00
Online Purchase	$10.00
Store Purchase	$6.98
Online Purchase	$279.00
Online Purchase	$3,195.62
Store Purchase	$11.43
Store Purchase	$43.20
Store Purchase	$1.98
Store Purchase	$2.99
Store Purchase	$13.98
Store/Online	$50.00
Approx. Total	$4,231.01
Grand Total	$7,885.62

Hybrid Rocket Assembly Instructions - DRAFT

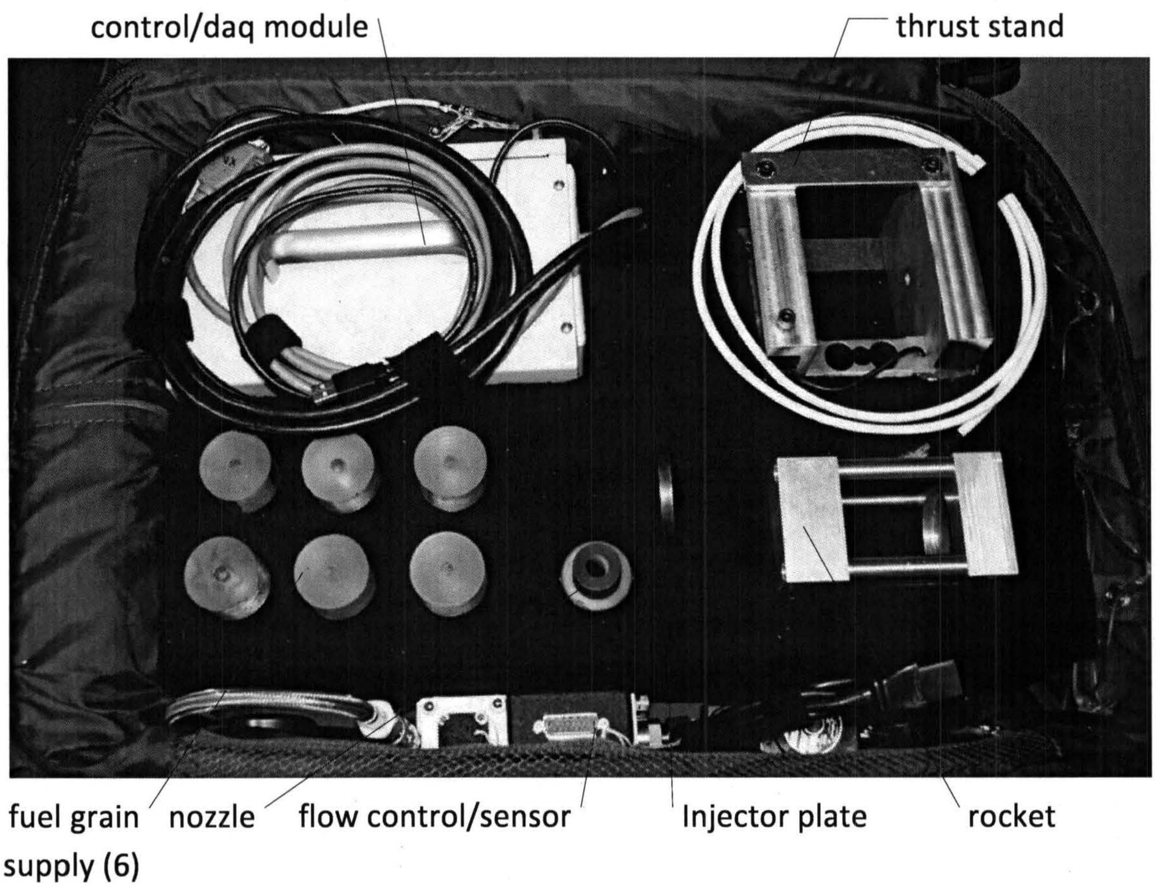
Required Equipment (supplied by host)

1. Gaseous oxygen tank and regulator.
2. Standard 120V ac power source and extension cord as needed.
3. Reasonably sturdy table.
4. Fire Extinguisher.

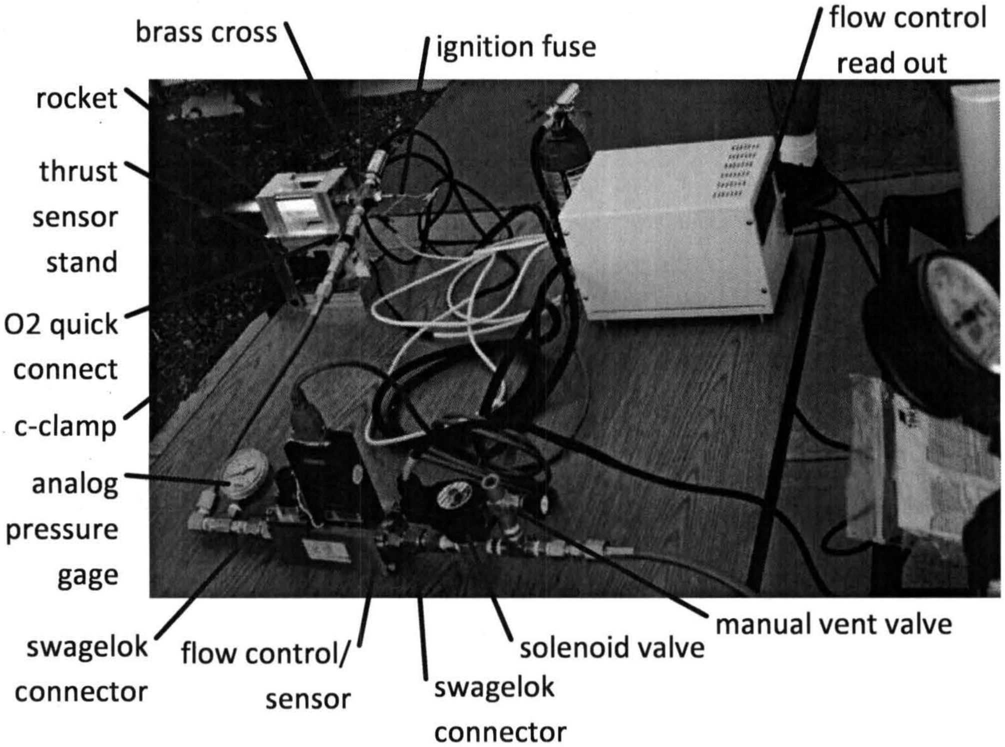
Assembly Procedure

1. Remove components from case.

   a. From the zippered compartments, remove the O2 supply plumbing, which connects the flexible line to a ¼"NPT brass cross, and to the pressure sensor. Also remove the tools.



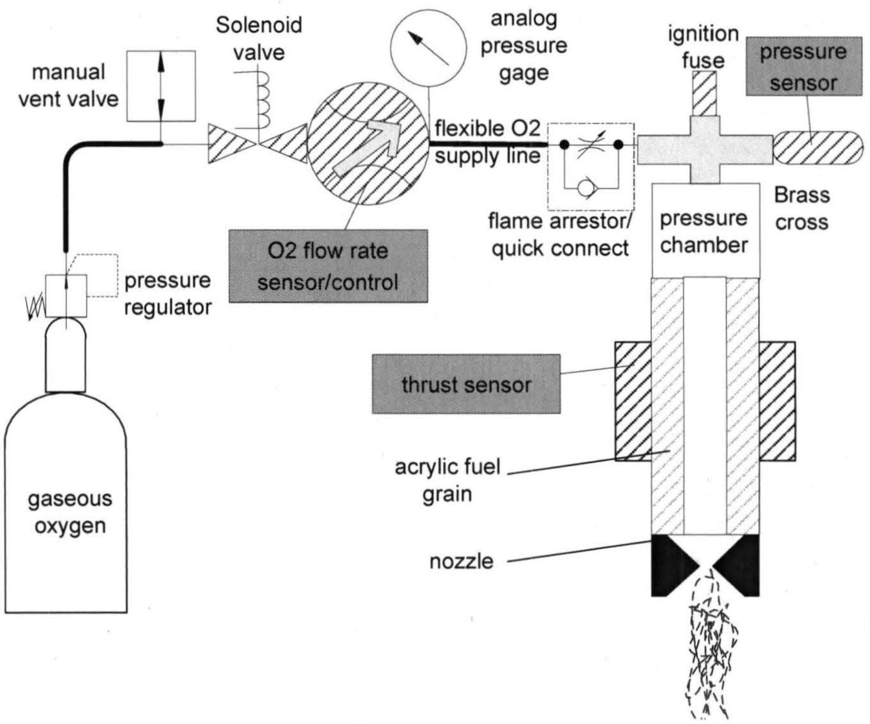
   b. Open the case, shown above, and remove the thrust stand, nozzle, injector plate, and rocket. Remove the control/daq module last. Position the components to be assembled as seen in the figure on page 2.



2. Assemble the rocket
   a. Remove the downstream plate from the struts
   b. Insert injector plate into the upstream plate, with the countersink towards the fuel grain
   c. Insert fuel grain into the countersink of the injector plate
   d. Place the Teflon washer between the fuel grain and the nozzle
   e. Place the downstream plate over the nozzle and secure to the struts using the supplied Allen screws
3. Thread the fuse wire into the fuel port and screw the nipple into the brass cross.
4. Connect 'quick-connect' oxygen line from the flow controller to the brass cross assembly
5. Secure rocket assembly to the thrust stand by means of Allen screws (finger tight)
6. Tighten the two stainless steel swagelok joints upstream and downstream of the flow controller/sensor
7. Secure thrust stand the table by means of a C-clamp
8. Connect the wiring: strain gauge, pressure transducer, flow controller, power cable, 'dead man' switch, solenoid valve, and USB cable
9. Attach the supplied regulator to oxygen tank
10. Connect flexible oxygen line from O2 regulator to the flow controller
11. Tighten swivel joints on the upstream and downstream side of the flow controller

12. Place the fire extinguisher at a ready location

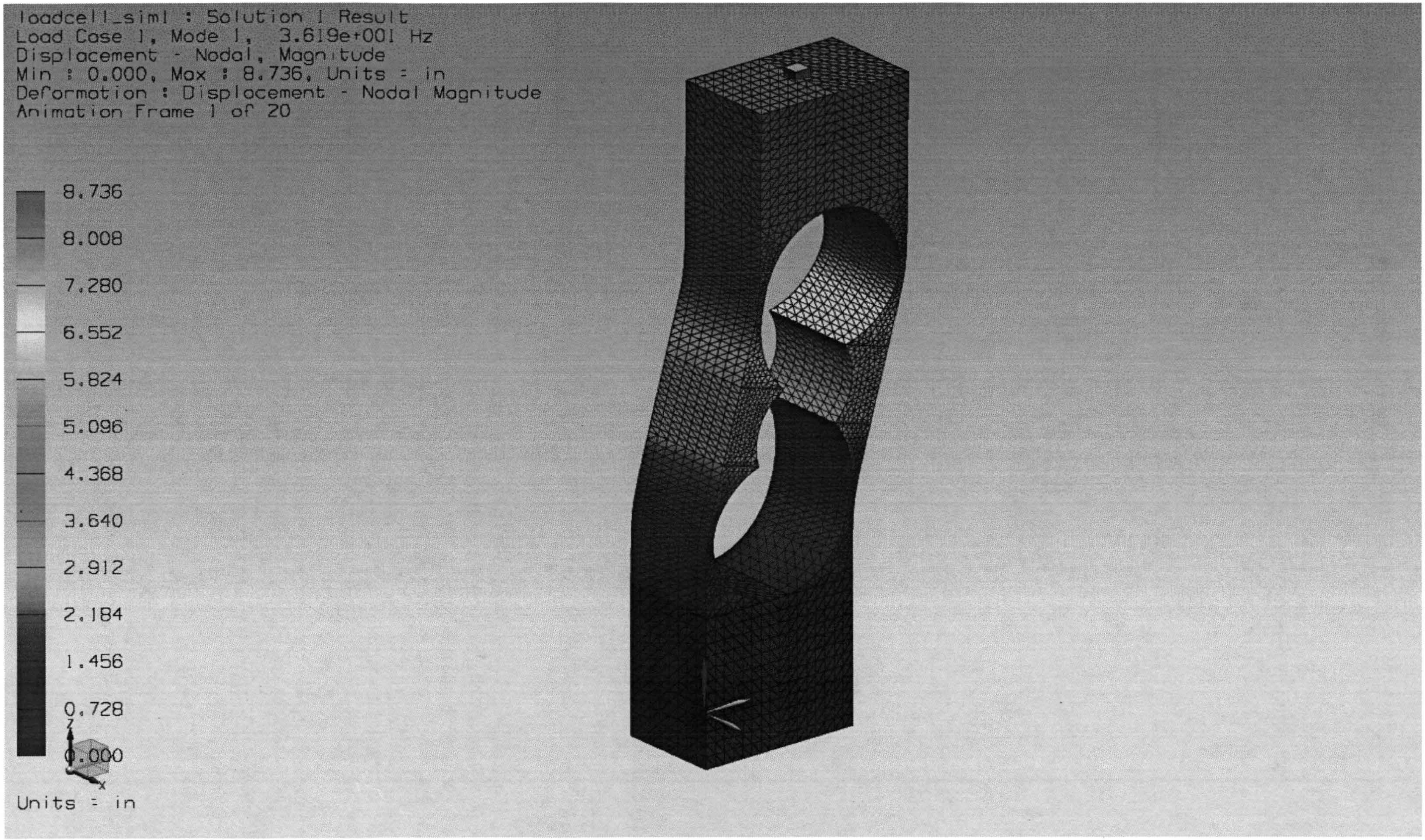
For reference, the figure below diagrams the O2 handling system.



Prepare for firing by following the Test Procedure Document.

Disassembly Procedure

1. Turn off main oxygen supply
2. Vent excess oxygen using the manual vent valve
3. Allow rocket to cool
4. Wearing gloves,
   a. disconnect the quick connect line from the ignition system
   b. remove rocket assembly from the test stand
   c. remove ignition assembly from the upstream plate
5. Disassemble the rocket assembly
   a. Remove diffuser, fuel, Teflon washer, and nozzle
   b. Attach the bottom plate to the struts and top plate to be stored
6. Disconnect all wires and roll them up
7. Disconnect oxygen line upstream of the flow controller
8. Loosen the stainless steel swivel joint downstream of the flow controller for storage
9. Replace the spent ignition fuse with a new one
10. Place all components into the case. The controller/daq module goes in first. Position it with the feet toward the side (or bottom) of the case and the permanently attached cables toward the dedicated cutout.


loadcell_sim1 : Solution 1 Result
Load Case 1, Mode 1, 3.619e+001 Hz
Displacement - Nodal, Magnitude
Min : 0.000, Max : 8.736, Units = in
Deformation : Displacement - Nodal Magnitude
Animation Frame 1 of 20
8.736
8.008
7.280
6.552
5.824
5.096
4.368
3.640
2.912
2.184
1.456
0.728
0.000
Units = in

Pre-Operation Safety Checklist

Ensure all items on this checklist are complete during or after the assembly procedure prior to operating the Portable Hybrid Rocket.

Required Item	Complete?
Fire extinguisher or equivalent Fire Suppression system present	
Test environment is well-ventilated and free of flammable materials	
All test participants wearing eye and ear protection	
Rocket engine fully assembled, all screws tightened	
Test stand firmly attached to flat, level surface	
Manual pressure relief (vent) valve is in the CLOSED position	
Oxygen hoses fully connected and verified free from leaks	
Rocket engine securely mounted on test stand	
All electrical connections are secure, no frayed or exposed wiring	
Emergency shutoff switch tested and verified to be functional	
All observers of the rocket are on the inlet side of the assembly (no observers in front of the exhaust plane)	

Hybrid Rocket Test Procedure – DRAFT revision 2

1. Five tasks are required. We have organized the test team this way:
   - Fire Watch
   - Deadman Switch Operator
   - Time Clock Operator
   - Data Recorder
   - LabVIEW Operator
2. Verify the Pre-Operation Safety Checklist is complete.
3. Conduct pre-test briefing: eye, ear protection; establish a clear area downstream of nozzle.
4. All test personnel record his/her name and on the Test Data Sheet.
5. **LabVIEW Operator,** first reset the O2 flow controller. Press 'mode' then ensure the daq system is operating. The three signals are load cell, pressure transducer, and flow rate.
6. **Data Recorder,** record the following on the Test Data Sheet:
   - Test number and current date and time
   - Test Location
   - Initial fuel grain weight
   - If applicable, model number of nozzle. If not, write **N/A**.
7. Rotate the O2 regulator control valve ccw in order to lower output pressure. Open the main O2 valve slowly. Rotate the control valve cw to approximately 40 psi.

The test may now begin

8. **Shutoff Switch Operator,** pull the trigger switch to open the normally-closed O2 solenoid supply valve.
9. **LabVIEW Operator,** perform the following steps:

   9.1. Using the instrumentation software, set the oxygen flow controller to the desired flow rate and allow the flow to stabilize.

   9.2. Record the following on the Test Data Sheet:
   - Data acquisition rate in samples/sec

- Stabilized oxygen flow rate value

9.3. Attach power supply to ignition system.

9.4. Verify the established clear area.

9.5. Begin data acquisition and verbally countdown to rocket ignition.

10. At the end of the countdown, **LabVIEW Operator,** ignite the rocket while the **Time Clock Operator,** begins the timer.
11. If an unforeseen event occurs, the **Shutoff Switch Operator** shall release the shutoff switch to terminate the test.
12. **Time Clock Operator,** provide the Shutoff Switch Operator with a verbal countdown or visual indication when the test time has expired.
13. **Shutoff Switch Operator,** when given notification to end the test, perform the following steps:

    13.1. Release the shutoff switch trigger to cut off the flow of oxygen to the rocket engine.

    13.2. Fully close the main supply valve on the O2 tank.

    13.3. Briefly open the pressure release valve to vent any residual O2 trapped in the system between the O2 regulator and the solenoid valve.

14. **LabVIEW Operator,** end data acquisition and save the file.
15. **Data Recorder,** record the following on the Test Data Sheet:
    - Duration of test, in seconds
    - Filename of current data set
    - Any additional comments or observations about the test
16. Once all test operations are complete and the hardware has cooled sufficiently (to the touch – roughly 20 minutes), disassemble the rocket, instrumentation, and oxygen hoses.
17. **Data Recorder,** if a scale is available, record the final fuel grain weight on the Test Data Sheet. If not, segregate the fuel grain for future analysis.
18. Remove the oxygen tank regulator and screw the valve stem cap onto the oxygen tank.
19. Place all hardware carefully into the foam inserts in the carrying case as outlined in the Assembly/Disassembly Procedure document.