AERO-PAC

AERONAUT

The Newsletter for the Association of Experimental Rocketry of the Pacific

Tripoli Rocketry Association, Inc. Prefecture No. 23

April 1992 Vol. 4 No. 2

AERO-PAC Seeks Alternatives to Fiberglass Insulation Recovery Wadding

Due to the environmentally sensitive nature of the Black Rock Desert, our primary launch site, the AERO-PAC Board of Directors recently initiated a program to promote the use of alternatives to fiberglass insulation, currently the most prevalent form of recovery wadding. The reason for this effort is a desire to prevent any possibility of the desert becoming "polluted" by a gradual accumulation of fiberglass wadding, which is virtually indestructible and does not break down due to natural forces, i.e. wind, sun, rain, etc. The Black Rock Desert is the premier launch site in the country for advanced high power rockets, and it is the responsibility of every rocketeer who flies there to preserve it and to protect its availability for our activities. AERO-PAC's ultimate goal is to eliminate all use of fiberglass wadding by the 1993 launch season.

In order to achieve this goal, AERO-PAC is considering the following steps to be taken. First, we must make all rocketeers aware of the significance of this effort, not only to preserve this launch site for our continued use, but because it is the environmentally responsible thing to do. Second, we want to encourage all rocketeers who are already using suitable alternatives to advise others of their experience, both informally to friends at the launch site, and through a letter or report to this newsletter or the *Tripolitan.* Third, further research must be conducted to determine the effectiveness and reliability of various recovery wadding alternatives, with a report of the findings published in the *Tripolitan* for the benefit of all Tripoli members.

We strongly encourage all rocketeers to take action now, starting with the summer 1992 launch season, to eliminate the use of fiberglass insulation wadding and to investigate the utility and convenience of alternatives. Without any comments on their relative merits, the following materials and/or approaches are offered for consideration:

- Estes wadding or a comparable biodegradable paper treated for flame resistance
- leafy vegetables, e.g. lettuce
- ejection baffles
- piston ejection systems
- flame-resistant fabric that acts as a "parachute protector" and remains attached to the rocket after recovery system deployment.

Technical Information Exchange

by Bill Lewis

Upscale

Information on a scratch-built, Wernher von Braun Orbit-to-Orbit 1992 1/48th scale model is featured in the March *Scale Modeler Magazine*. This model is for a national exhibit entitled "Blueprint for Space," that will be traveling around the country in 1992 and 1993 as part of the International Space Year (ISY). Story by David D. Merriman, Jr.

Information on building a large-scale version of the Space Shuttle was featured in the February 1992 *RC Modeler Magazine*. This article, although adapted for a "pull prop" cavity design, offers some good basic design considerations for the rocketeer who wants to build a large upscale Shuttle. Author and builder Parker Leung took five years and four complete models to reach the current stage of his construction. Plans are available from *RC Modeler Magazine*.

Aluminum Finish Look

An article entitled "Authentic Aluminum" by Clarke Smiley describes a procedure using balsa sheet, Sig Supercoat Dope and aluminum paste/powder to achieve a shiny surface that "makes your model look like it just emerged from the factory;" and it will retain its finish - no polishing necessary. This article appeared in the March 1992 issue of *Model Airplane News*.

Servo Operated Compact 35 mm Camera

This appeared as a feature titled "The Paragon Continues" by Dave Garfield in the March 1992 *RC Modeler Magazine*. In this article, a Paragon fuselage is expanded to accommodate a compact 35 mm camera that looks out the side of the aircraft, providing the view that a passenger would see.

Hot Wood

An article titled "Zip R/C" by Pete Mathis in the October 1991 *RC Modeler* gives information on building a fuselage by ironing webbing with a standard home fabric iron, using a jig and tape to hold the balsa/webbing in place. The webbing is called "wonder web" and costs $1.00 per yard at a 17" width. This technique has definite applications for nose cones, transitions, and other compound surfaces encountered by the rocketeer.

ESIEE Space

On July 17, 1991, a radio astronomy satellite named SARA was launched aboard an Arianespace launch vehicle. What was unique about this launch was that the satellite was built by a club at the French "Ecole Superieure d'Ingenieurs en Electrotechnique et Electronique," called ESIEE Space, that was originally founded to build and launch experimental rockets. SARA is designed to listen to Jupiter's radio emissions in the 2-15 MHz range and transmits telemetry on 145.955 MHz, an amateur frequency band. From HAMSATS, October 1991 *Amateur Radio Today*.

Erik's Rocket

In the April/May 1992 issue of *Air and Space Smithsonian* is an article about Erik Wilkinson, written by his uncle, Stephan Wilkinson. It is an interesting story about Erik growing up with model rockets, and then going on to launch high altitude sounding rockets at New Mexico's White Sands Missile Range under a graduate grant while at the University of Colorado. The sounding rocket is a Black Brant IX perched atop a Terrier booster. Pictures of the rocket and payload diagram and an inset on NASA's sounding rocket program are included.

AERONAUT

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AERO-PAC

1992 BlackRock Desert Launches

EVENTS SCHEDULED:

Tripoli Sanctioned Launches

May 16-17 Aeronaut III
July 11-12 BlackRock IV
August 13-16 LDRS XI

Note: Aeronaut III & BlackRock IV will be supporting The National Student Payload Launch Program as part of International Space Year (ISY).

Non-Tripoli Sanctioned Launch

*August 17 Fire(BALLS) 02 **
Experimental-Unlimited Launch

*A Separate Package specifying Rules, Safety Code and disclaimer requirements available March 31, 1992.

AERO - PAC

VERY IMPORTANT! PRE-REGISTRATION IS A MUST!

LAUNCH PACKAGE-**$1.00** REGISTRATION FEE BY MAIL-**$5.00**

(LAUNCH PACKAGE INCLUDES REGISTRATION FORMS AND FAA FORMS)

REGISTRATION FEE AT LAUNCH-**$10.00**

RANGE FEE-**$5.00** PAYABLE AT LAUNCH

ALL FEE'S ARE **PER FLIER NO EXCEPTIONS.**

(REGISTRATION FORMS & FAA FORMS WILL ALSO BE AVAILABLE FROM THE AERONAUT NEWSLETTER OR YOUR LOCAL PREFECTURE.)

TRIPOLI SAFETY CODE WILL BE STRICTLY ENFORCED

FOR LAUNCH PACKAGE SEND TO:

RONALD DEVINE, LAUNCH DIRECTOR
20161 WISTERIA ST. APT. 8
CASTRO VALLEY, CA 94546

Club News

Range Fee Discounts

Just a reminder that all current AERO-PAC members are eligible for a $2.00 discount on **range** fees (payable at the launch site) for each of the upcoming AERO-PAC sponsored launches, Aeronaut III and Black Rock IV. Flyer's Information Packets, containing a registration form, FAA "rocket-listing" forms, and other pertinent information, were recently sent out to all AERO-PAC members and Tripoli prefectures.

New Members

Welcome to the following new AERO-PAC members who have joined our ranks since January, 1992:

Sven Schwartz
Peggy Gearhart
Paul Campbell
Paul Boulay
Michael Saltern
Chet Geyer
Frank D'Agosta
Michael T. Maddox

The AERO-PAC membership list (with addresses and phone numbers) appears elsewhere in this issue, but includes only those whose memberships are **current** for 1992, (34 to date). If you're not on this list and want to be, please renew! (An application appeared in the last issue of the *Aeronaut*).

Classified Ads

As a free service to its members, AERO-PAC will begin accepting classified advertisements (of a non-commercial nature only) for publication in a special section of the newsletter. To submit your ad or to get more information, please contact the editor.

FAA Information

A thank you letter for the FAA's support for the four launches held at Black Rock in 1991 has been sent to Thomas Moody at the Hawthorne Western Regional Air Traffic Division, as well as to Gus Overston at the Oakland Flight Control Center in Fremont. Also contained in the letter was a presentation of the plans for the 1992 launch agenda including the Fireballs event. The FAA has issued Waivers/Authorizations and supported AERO-PAC's launch requests dating back to our first launch (Aeronaut I) in May 1990.

An application for Waiver/Authorization has been filed with the FAA for a blanket 20,000 feet AGL, from sunup to sundown for the May 16-17 Aeronaut III Launch. In addition to the blanket request, two three-hour windows for 50,000 feet AGL have been requested from 9-11 AM and from 2-3 PM each day.

BLM Information

A letter and phone call follow-up requesting clarification on our 1992 "benchmark survey" has been answered by Jeff McCusker of the BLM's Winnemucca office. Basically this letter gives approval for the two Regional/National invitational launches (Aeronaut III and Black Rock IV), but requires formal application for the LDRS/Fireballs event. Bill Lewis, AERO-PAC Commissioner, has sent an outline to pertinent members of the Tripoli Board of Directors outlining the requirements that Tripoli must meet prior to filing this year's application, as well as the stipulations for this year's event.

Of particular note was the lack of trash control at the campsite area. AERO-PAC members should take special notice of this situation and "police" their campsites, while reminding their camping neighbors to do the same. If we fail to handle this correctly, we could find ourselves looking elsewhere for a launch site!

International Space Year (ISY) -1992

AERO-PAC's Tripoli-sanctioned launches, Aeronaut III and Black Rock IV, and Tripoli's LDRS XI Nationals have been listed as part of "Project Outreach" in the latest ISY National Directory. These launches will give special considerations to students and faculty for payloads and launch vehicles as designed and built by high school, college, and university students. Chuck Mund heads up the Project Outreach program.

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Club News, from page 4

AERO-PAC is also planning an ISY rocket mail cover launch at Black Rock IV, similar to last year's event at Aeronaut II. Information on orders for this exclusive cover will appear in the next issue of the *Aeronaut*.

Board of Directors Meeting Minutes January 12, 1992

Attendees: Ron Devine, Jim Gearhart, Peggy Gearhart, Bill Lewis, Pius Morozumi

Meeting called to order at 10:07 AM

I. Reading of the November 3, 1991 board meeting minutes

II. Overview of documents presented to all board members. Bill recommended using other prefecture's newsletters in *Aeronaut*. Jim will write to editors for permission to use material.

III. Financial Status
- A. Four new members joined AERO-PAC at general assembly meeting held on November 17, 1991.
- B. Bill will balance books and schedule separate meeting to transfer duties of Treasurer to Peggy.

IV. Launch Direction
- A. All equipment has been checked, tested, cleaned.
- B. Four micro-clips replaced.
- C. Ron composed and distributed an inventory list that will also be published in the *Aeronaut*; some equipment is missing due to transfer of duties from Phil Hayton to Ron.
- D. Proposal approved to have Phil buy out AERO-PAC for equipment he still has or return it to the club.
- E. Board agreed to Dana Gass's request for an additional $500.00 for equipment/services.

V. Equipment Acquisitions
- A. Board approved the purchase of a P.A. system with two microphones.
- B. Pius will buy a first-aid kit and fire extinguisher(s) with the funds allocated by the board.
- C. Ron will price asset labels for AERO-PAC property; findings will be presented at the next board meeting.
- D. Bill will make launch stands with collapsible tubing that he will present to the board.

VI. Future Launches
- A. Layout of launch site set-up will be presented at next meeting.
- B. Bill will propose changes to FAA in the requirement so that he may handle the forms locally and document them here prior to forwarding to FAA.
- C. Jim and Peggy will develop new format of flight cards to be reviewed and approved at the next meeting.
- D. Ron will revise launch announcements and send to prefectures and hobby stores.
- E. Board member will look into a spring launch at the Lost Hills site to "get in the door" at that location.
- F. Point Reyes will be investigated as a possible site for the launch of lower-powered motors.

VII. *Aeronaut* Newsletter
- A. Jim has developed a schedule for 1992 that will be published in each issue of the *Aeronaut*.
- B. Additional copies of the newsletter will be sent to Pius and Bill to distribute to hobby stores.

VIII. Miscellaneous
- A. An equipment checklist for launches will be developed.
- B. Fireballs 002 was discussed and Bill will send a letter to rocket groups describing the launch; further discussion at next meeting.

Meeting adjourned at 1:41 PM.

Board of Directors Meeting Minutes February 23, 1992

Attendees: Ron Devine, Jim Gearhart, Peggy Gearhart, Bill Lewis, Pius Morozumi, Walt Rosenberg

Meeting called to order at 10:23 AM

I. Reading of the January 12, 1992 board meeting minutes.

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Club News, from page 5

II. Overview of documents presented to all board members.

III. Launch Site
   A. Ron will continue to attempt to get in contact with Bernard Ethier regarding the proposed investigative launch at Point Reyes.
   B. Motion approved to set launch date at Point Reyes for April 18, 1992.
   C. Bill is currently awaiting a response to his letter regarding a possible launch at the Lost Hills site; an update will be made at the next meeting.

IV. Launch Equipment
   A. Ron will continue pricing asset labels for the prefecture. He will contact Aerotech for a possible donation of labels. Walt will follow up with his employer as a viable alternative.
   B. Porta-potties for Aeronaut III will be transported by Jeff Boyle. Ron will be responsible for transporting the facilities for the Black Rock IV launch if no one volunteers. The board approved a motion to reimburse the volunteers for the purchase of a hitch (ball) at a cost of approximately $18.00.
   C. Bill and Ron will compose an article on the launch system to be published in an upcoming issue of the *Aeronaut*.
   D. Pius and Ron will submit a proposal for the launch system at the next board meeting.
   E. "Launch Director" checklist will be presented at the next board meeting.
   F. Bill distributed sketches of his proposed launch stand and further described his design for the portable/collapsible stand. Pius's proposal to have Bill present a prototype at the next board meeting was approved.

V. Editor's Report
   A. A sample of the new flight card was reviewed and approved by the board. Jim will add the AERO-PAC logo to the card and will amend the card to include verbiage indicating the requirement of a tracking sheet if the flight is to be tracked.
   B. Jim will provide the board at the next meeting with an update on advertising in the *Aeronaut*.
   C. Material to be included in the April issue of the *Aeronaut* was discussed.

VI. Financial Report
   A. The duties of the treasurer were passed from Bill to Peggy.
   B. The format of membership cards will remain the same, as discussed by the board members.

VII. Miscellaneous
   A. Walt will create and distribute meeting announcements to all AERO-PAC members, various potential members, and hobby stores.
   B. Bill is following up on possible discounts at hobby stores to all AERO-PAC members.
   C. Ron presented a sample of the advertisement that will be published in the *Tripolitan*.
   D. The next board meeting will be held April 18, 1992.

Meeting adjourned at 1:21 PM.

Board of Directors Meeting Minutes April 26, 1992

Attendees: Ron Devine, Jim Gearhart, Peggy Gearhart, Bill Lewis, Pius Morozumi, Walt Rosenberg

Meeting called to order at 9:20 AM.

I. Overview of documents, agenda.

II. Reading of the February 23, 1992 board meeting minutes.

III. Financial Status/Membership
   A. Balance of $494.15 in checking account
   B. 32 total members to date, with eight new members in the club
   C. Walt sent membership applications to 31 potential members (obtained from Tripoli Yellow Pages).
   D. Pius will contact Tim/Wilma Nicholls for additional names to contact.

IV. Launch Status
   A. It was confirmed that Jeff Boyle will transport porta-potties to Aeronaut III launch
   B. Launch equipment has been tested; new boxes work well.
   C. Board approved allocation of $129.87

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Club News, from page 6

to Pius for purchases used to amplify first box and develop a second box.

D. Pius donated one marine battery to AERO-PAC. The battery was given to Ron for handling.

E. Launch equipment checklist developed by Ron; will be put into computer and faxed to all board members.

F. Ron will attempt to contact Phil Hayton to finalize "loose ends."

G. Bill, Ron, Dave Bucher will collaborate to build wooden, "disposable" launch stands.

H. Ron will contact Tim Brown to get launch rods if Dave does not have any.

I. Jim will complete launch date sheet, make copies, and distribute to board members for duplication.

V. Miscellaneous

A. Pius's proposal that all AERO-PAC-sanctioned launches allow only biodegradable wadding was approved by the board. The new requirement will begin with the Black Rock IV launch. A list of wadding alternatives will be given to all AERO-PAC members, and AERO-PAC will have a supply to sell at 1992 launches.

B. Bill will also send a letter to Chuck Rogers requesting the opportunity to provide biodegradable wadding at LDRS XI. The board intends to announce the new requirement at Aeronaut III, enforce it at Black Rock IV, and make alternative wadding available at LDRS XI.
(Editor's Note: This policy was subsequently revised; see page 1 of this issue).

C. Bill gave the board an overview of his letter presented to Chuck Rogers and other Tripoli board members regarding AERO-PAC's involvement at LDRS XI.

D. Peggy will purchase trash bags to provide to campers at 1992 launches.

E. Ron's proposal was approved to have three signs made for the campground describing rules, etc.

F. The next board meeting will be held June 21, 1992 at the Gearhart's.

The meeting was adjourned at 11:30 AM.

Financial Statement

SUMMARY- SIX MONTHS ENDING 12-31-91

BALANCE	BROUGHT FORWARD FROM 6-31-91	$319.60	
JULY 1991	Paid check 109 Rocket Mail Printing	-$ 65.38	
	Paid check 110 AERONAUT Pub. cost	-$ 31.73	
	Balance July statement	$222.49	(7)
AUGUST 1991	PAid check 111 Sani Hut Porta Potti(BR II)	-$ 65.00	
	Paid check 112 Post card mailing J. Gearhart	-$ 4.56	
	Deposit receipts Fireballs Reg. (8-21-91)	+$211.00	
	Deposit receipts " " (8-21-91)	+$153.00	
	Deposit receipts-Black Rock III (8-21-91)	+$316.00	
	Balance August statement	$832.93	(8)
SEPTEMBER 1991	Paid check #13 1st payment launch equipment to Dana Gass (9-9-91)	-$250.00	
	Deposit cover and patches income (9-9-91)	+$ 54.00	
	Debit withdrawl, bad check (8-26-91)	-$ 9.00	
	Balance September statement	$627.93	(9)
OCTOBER 1991	Paid check 103 Sept meeting announcement (J. Gearhart)	-$ 5.13	
	Paid 114 Tape Proj. (David Cotriss)	-$ 14.23	
	Deposit Fireballs cash & check repayment (10-2-91)	+$ 39.00	
	Deposit sale socket mail covers (10-23-91)	+$200.00	
	Deposit Membership & covers sale money	+$ 27.00	
	Balance October statement	$874.57	(10
NOVEMBER 1991	Paid check 115 2nd & 3rd quarter operating cost (W. Lewis)	-$ 58.57	
	Paid check 116 2nd payment launch equipment (D. Gass)	-$500.00	
	Paid check 117 Gen Assembly meeting cards (J. Gearhart)	-$ 4.75	
	Deposit check D. Cook, Balck Rock III	+$ 6.00	
	Deposit check receipts fro 11-17 meeting	+$ 73.00	
	Balance November statement	$390.25	(11
DECEMBER 1991	Deposit reconcilements of funds (D. Cook)	+$ 64.00	
	Balance December statement and 2nd half 1991	$454.25	(12

NOTE:

1) Several deposits are outstanding regarding launch fees, membership and contested equipment-estimated value of these monies are $110.0
2) Separate statements regarding operating cost for all quarters to which payments were made have been posted in financial book.

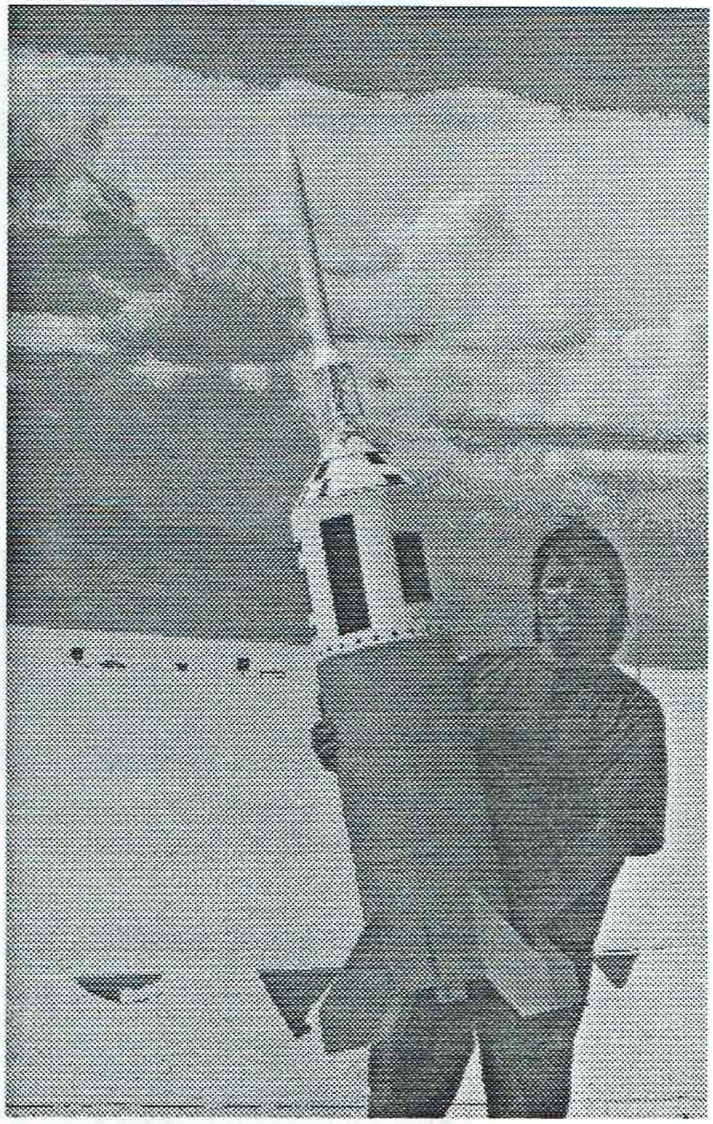
SUBMITTED BY:
William D. Lewis
January 23, 1992

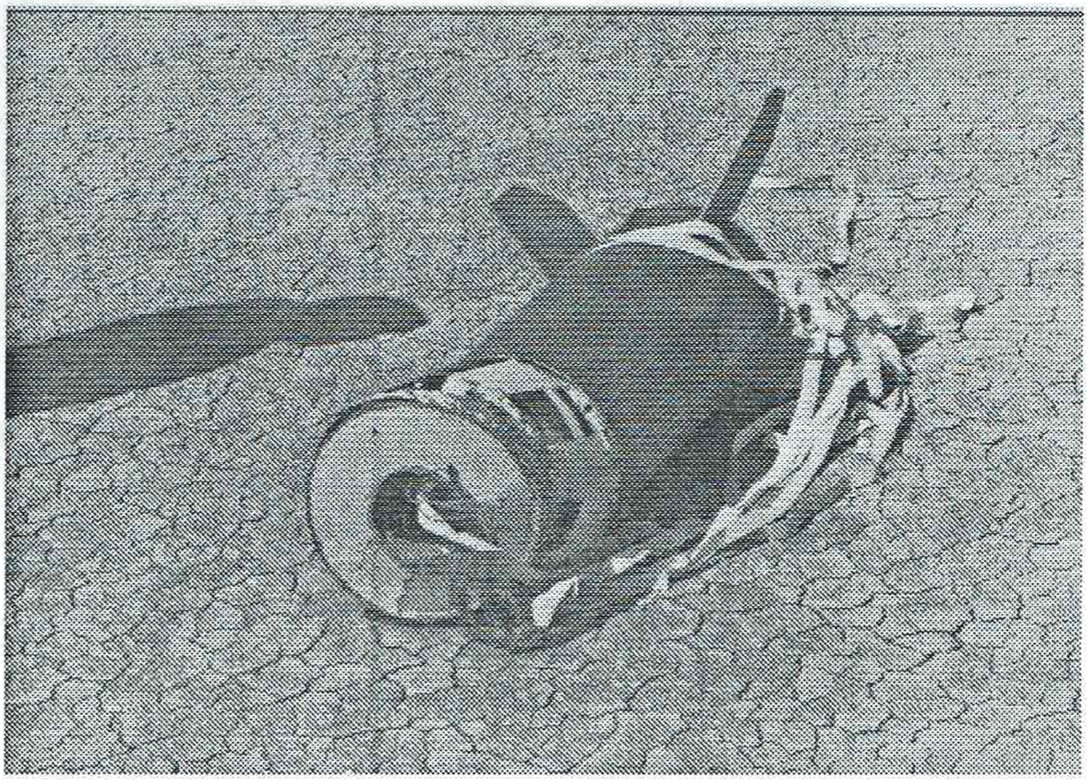
Black Rock III

Photos and Naration by: Bill Lewis Scanning and layout by: Ron Devine

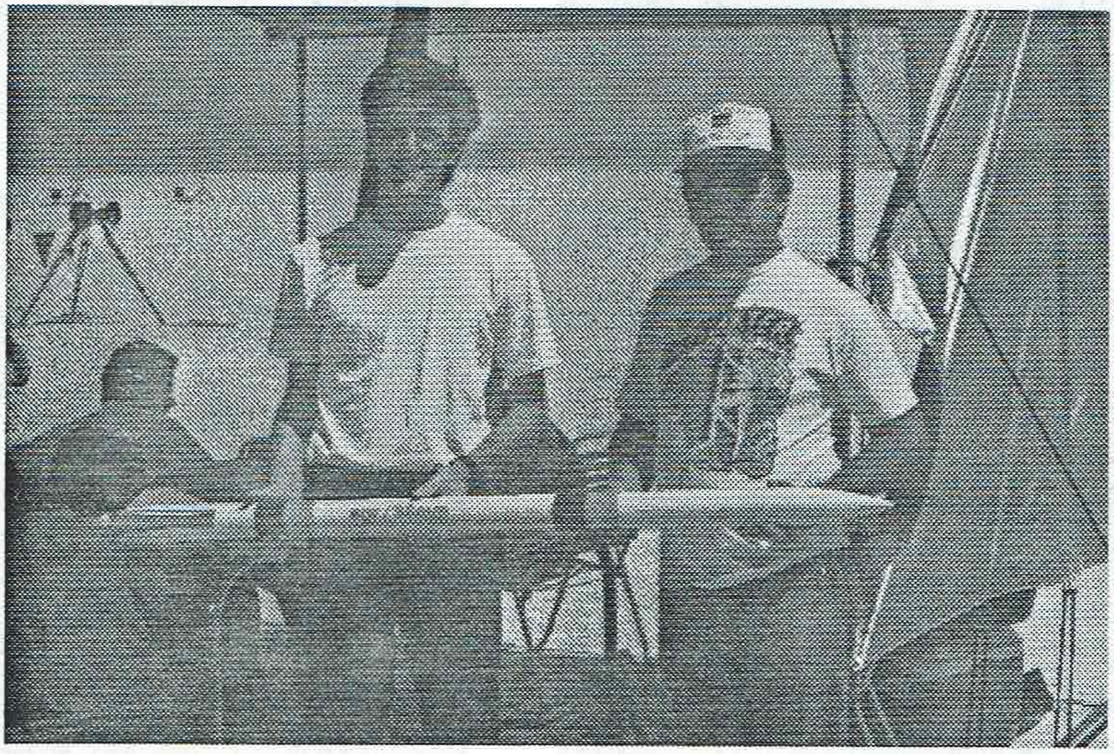
Dave Bucher of Gualala, CA "LiL Joe" with "Rocket Holder".

RSO Bill Lewis and Jim Gearhart weigh in rocket.

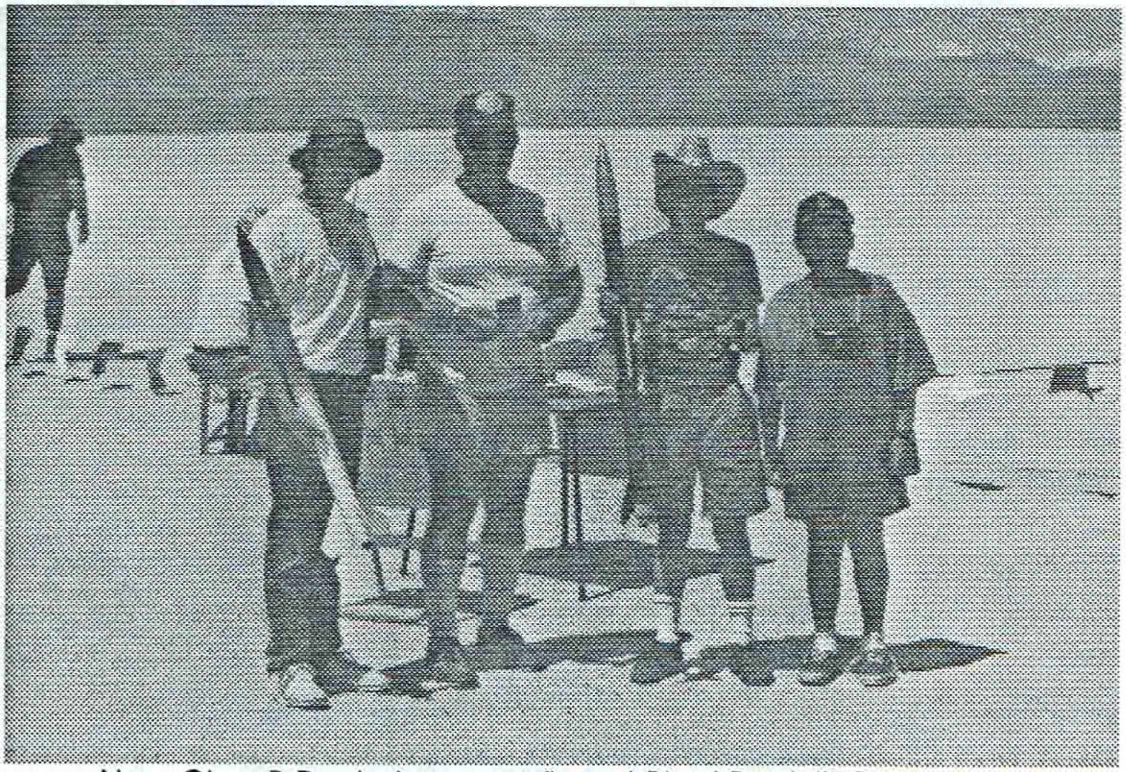




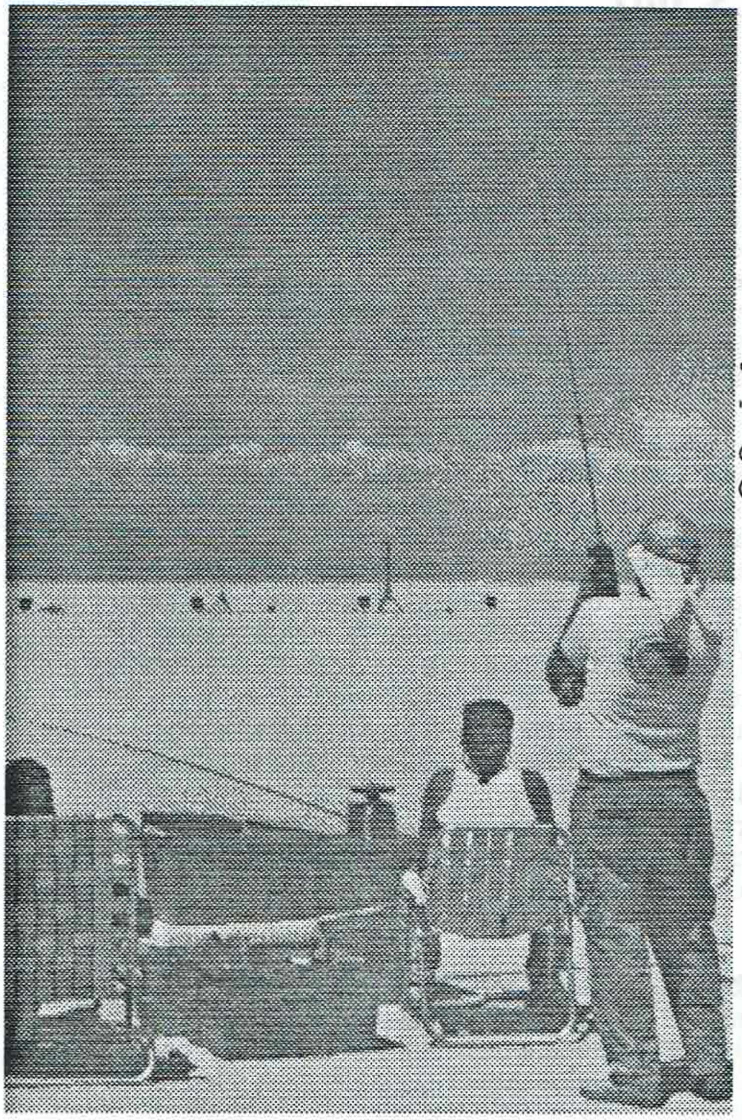
Dave Bucher's 'LiL Joe'
Before and after Photo's.



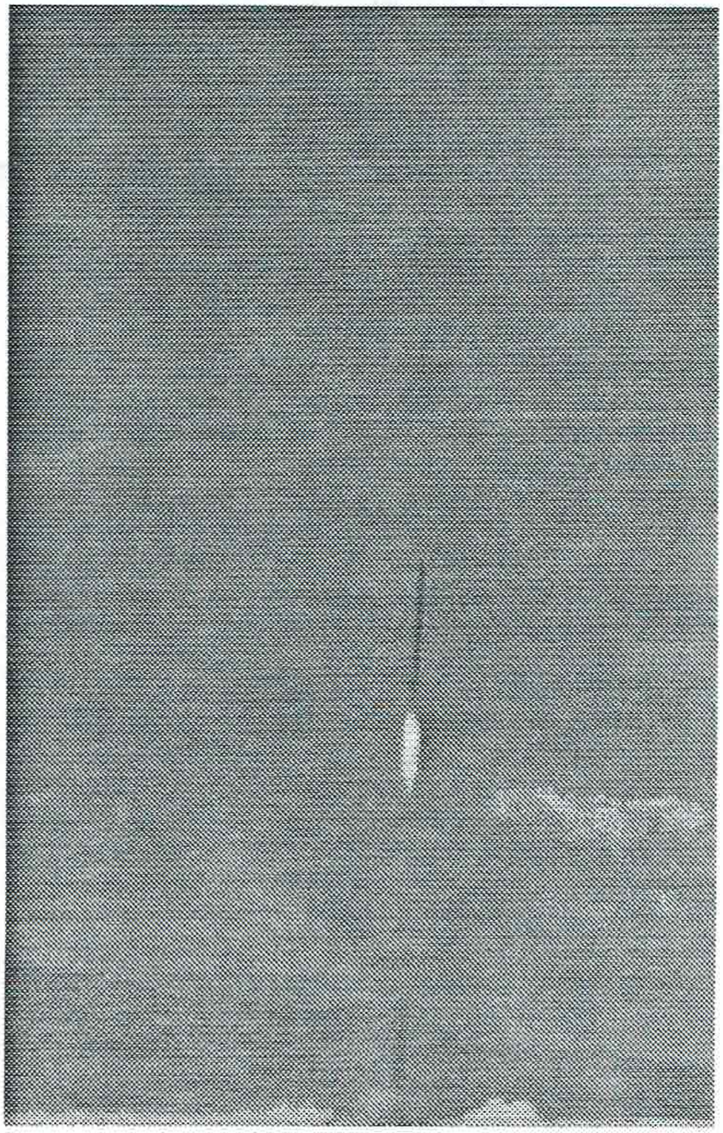
Chris Smith of Modesto, CA - with Jerry Irvine of U.S. Rockets.
Ready to fly rocket with prototype 'J' motor.



New Class B Rocketeers confirm at BlackRock III. Rod Howden of Saratoga, CA (on the left). Pius Morozumi & son John of Morgan Hill. Rod & Pius confirmed at BlackRock III and John at LDRS X. Aero-Pac prefect Bill Lewis does the honors.



"Uncle" Bob Baker of Lucerne Prefect Fame and his 'L' power rocket attempts a BlackRock series altitude record using Rick Loehr's Space Dynamics - Onboard Altimeter/ Transmitter System.



Reported altitude exceeded 19,000 feet.

FIREBALLS 001

AERO-PAC's First Experimental Unlimited Rocket Launch

by Bill Lewis

On August 19, 1991, the first experimental-unlimited launch in the Northern California/Nevada region was held by AERO-PAC, a prefecture of the Tripoli Rocketry Association. This launch followed in the tradition of the great Smoke Creek Desert launches held during the late 1970's and early 1980's, as well as of the Mojave Dry Lake launches made by several amateur rocketry organizations from about 1940 through the 1960's.

For this launch, Fireballs 001 was granted an FAA altitude waiver of 100,000 feet above ground level (AGL), which I believe is the highest altitude granted to a non-commercial rocket organization since the Rocket Research Institute launched at Smoke Creek in 1987.

The impetus for this launch came from several sources. First there were the original plans for a "Balls" launch, as conceived by Steve Buck of High Sierra Rocketry and Tim Brown of West Coast Rocketry, in a discussion during the Black Rock II Launch in 1990. This launch was planned as a limited event for rockets utilizing 1300 Newton-seconds or more of total impulse (K motor or better). The launch date was never set, although it was envisioned for summer 1991. I was brought into the picture when I was asked to support this launch with an appropriate application to the FAA for authorization and waiver. This planning started before the decision came down from Tripoli headquarters to hold LDRS X at Black Rock.

AERO-PAC was already committed to the Black Rock III Launch to be held on July 20-21, 1991, and was anxious to try out its new launch system in a full ten-pad or greater configuration, before committing to support LDRS. At the Winterfest 1991 Launch at Lucerne, Tim, Steve, and I got together briefly to discuss general possibilities, including having AERO-PAC host the launch as a non-sanctioned event, in the same manner as Lucerne was currently conducting its launches. I believe it was at this meeting that Steve suggested that the launch be held on the Monday following LDRS.

After conferring with the AERO-PAC Board of Directors, and following a short discussion with Chuck Rogers, I sent a letter to the FAA regional control office in Hawthorne, thanking them for their support in 1990, and informing them of the intended AERO-PAC launches to be held in 1991. This letter contained the basic plans and information on the launch now referred to as "Fireballs."

The second impetus for this launch could be classified as nostalgic. I had kept in touch and made some recent contacts with several individuals within the amateur experimental rocketry community. Through this exposure, I was aware of the current activities of such organizations as the Reaction Research Society (RRS - Mojave Test Area), the Rocket Research Institute (RRI - "Rocket Research Gang"), the Pacific Rocket Society (PRS), Starflight, and the Independent Rocket Society (IRS). Tom Blazanin, former president and a founder of Tripoli, was also trying to get amateur experimental activities into Black Rock with the idea of a "Black Rock Society."

When I received a phone call from Dean Oberg of Space Delivery Systems (SDS) in Buffalo, New York, I quickly realized that Fireballs was being interpreted beyond the scope of high impulse commercial rocket motors (especially as a fallback for motors without certification, as Chuck Rogers had envisioned the launch). Apparently, the word had spread and several organizations such as SDS were looking to utilize the Fireballs launch as a site to test their "custom" motors. In Dean Oberg's case, this was a hybrid propellant motor with the capability to reach 65,000 feet altitude. In my discussions with Dean, I asked him to send me a set of drawings for presentation to the AERO-PAC Board. At the next Board meeting, the proposal was unanimously approved, under the assumption that I would handle the liquid fuel and hybrid rockets under a format different from the "standard" high power rockets flying with and without certified motors.

Shortly after talking to Dean Oberg, I received a phone call from George Morgan of the Pacific Rocket Society, who indicated that they would have a large liquid fuel rocket available that was capable of reaching 100,000 feet

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FIREBALLS, from page 12

altitude. Based on information presented on these two rockets, an application for a waiver to 100,000 feet was prepared and submitted to the FAA.

As it turned out, neither the hybrid nor the liquid fuel rocket materialized for this event. Other rockets that were registered for this event ended up being launched at LDRS X. Some individuals registered for both LDRS and Fireballs, on the assumption that if Tripoli changed its mind on the motor use policy, then they would launch at LDRS; if not, then Fireballs was the answer. As it turned out, Tripoli backed down on their earlier motor certification policy and allowed motors as previously specified by an approved manufacturer to be utilized. This left Fireballs with a somewhat shortened schedule.

The first rocket on the pad was Rick Loehr's two-stage, telemetry downlinked vehicle powered by 2 L motors in the booster and one L in the upper stage. This rocket was already being prepped when Ron Devine, my son Dean, and I arrived to start the event. After receiving signed "disclaimer/release" forms from Rick and announcing the requirements for the launch over the loudspeaker, we were ready to proceed. Rick's rocket brought everyone to their feet as the twin flames from his custom Space Dynamics L motors lit up the morning sky.

Soon many rockets were being brought forward, and a link was established between the Rogers-Wood-Brennion & Co. tracking contingent and the rangehead, which was manned by ham radio operators Mark Curtis (WE8K) and Phil Saeli (N2IWR).

Although no records were broken during this launch event, and many individuals expressed disappointment at not seeing the hybrid or liquid fuel rocket fly, most people were content with the results. These included a few like Dale March who just brought custom motors to static test fire.

I would especially like to thank Ron Devine, Dean Lewis, Bob Baker, Jay Orr, and Kelly Badger for their RSO/LCO support and for making the event run smoothly.

Currently, a second Fireballs (002) is being planned for Monday, August 17, 1992, following LDRS XI. This plan has received complete support from the Tripoli Board of Directors, who unanimously voted to support this event (through cooperation with AERO-PAC) as a follow-on to the sanctioned LDRS. In 1993, as LDRS moves eastward, the Fireballs 003 event will be planned differently, and will take on a different significance with western regional rocketeers.

In the meantime, Fireballs 002 should offer a different slate from 1991, with the Tripoli motor certification policy having been sorted out. Mark your calendars for Monday, August 17, and stay for a good time to see some interesting rockets fly! (Besides, you can drive home under better traffic conditions than during the Sunday evening rush).

The following is a list of Fireballs 001 tracking results, as compiled by Charles Rogers and Fred Brennion.

Name	Rocket	Dia. (in.)	Len. (in.)	Wgt (lbs)	Motor(s)	Altitude (feet)	Error
Bill Morrow	Ejaculator	2.13	84.0	18.00	USR L1000-25	16,376	13.6%
Sienkiewicz/Bolduc	Mach Buster	4.13	73.5	13.75	Vulcan L750	13,743	1.3%
F. Kosdon/B. Baker	Starfinder	2.80	84.0	16.00	Kosdon L1350	12,128	0.4%
Mark Clark	Swift	2.70	55.0	8.25	Aerotech K550	11,467	0.6%
F. Kosdon/B. Baker	Starfinder	2.80	87.0	16.50	Kosdon L600	11,106	0.3%
Jay Orr	Titan	2.70	72.0	10.00	USR K250	10,974	0.1%
Jim Cotriss	Experimental Ionosphere	2.26	43.5	6.50	Aerotech K250	10,826	3.0%
Neil Fishman	ARC Scorpion	4.00	72.0	13.00	Vulcan K500-15	9,297	3.0%

Approximate Closed-Form Flight Performance Prediction Equations

by Jim Gearhart

Summary

In this article, a set of equations are derived that can be used to estimate the flight performance of a single-stage model or advanced high power rocket, including calculations of the burnout altitude and velocity, the coast time to apogee, and the peak altitude. The assumptions made in this analysis are described, the results of some sample calculations are provided, and the use of altitude tracking data to estimate a rocket's actual drag coefficient is discussed. A formula for correcting the air density to the launch site altitude and ambient temperature is also given.

These equations represent the closed-form solutions of approximate equations of motion governing a rocket through the boost and coast phases of a vertical trajectory. They can be readily coded up on a programmable scientific calculator and provide a quick means of estimating the peak altitude and the optimum delay time for a given motor type.

The particular solution approach presented here is attributable to the analysis first performed by Douglas J. Malewicki and (independently) by Leonard G. Fehskens in 1968, as reported in Ref. 1. This article is intended as an historical review of this previous work, (the results of which can also be found in old Centuri and Estes technical reports, Refs. 2 & 3), in order to make it available to rocketeers who may not have ready access to these sources. However, some of the equations presented here are my own extensions of the original analysis.

Introduction

In general, the dynamics of a rocket vehicle are extremely complicated, in that we are dealing with a body that has time-varying mass and inertia properties, moves through a variable atmosphere and a non-uniform gravitational field, and has time-dependent forces and moments exerted upon it by the rocket thrust, aerodynamic lift and drag, and various random disturbances. The general equations of motion governing its trajectory are a coupled set of six second-order ordinary differential equations, three for the translational degrees of freedom (i.e. the position of the mass center), and three for the rotational degrees of freedom (i.e. the attitude of the assumed rigid vehicle). In addition, an auxiliary first-order equation is needed for computing the mass of the rocket as the propellant is expended.

Generating these governing equations is a straightforward process, although the accurate modeling of the aerodynamic forces and moments poses special problems. The dimensionless aerodynamic coefficients appearing in these terms are functions of the vehicle shape and configuration relative to the incident airflow, as well as the compressibility, viscosity, and other physical properties of the air. These coefficients can be estimated through a wide range of techniques, both experimental (e.g. wind tunnel and flight testing) and theoretical (e.g. computational fluid dynamics). Ref. 4 is an excellent source of data and formulas for estimating the drag coefficient of a model or advanced high power rocket.

Investigating the theoretical flight performance of a particular rocket vehicle (e.g. for the purpose of maximizing the altitude for a given payload mass), requires solving the differential equations of motion, which can, in general, be achieved only through numerical integration techniques using a digital computer.

Fortunately, for our purposes in model and advanced high power rocketry, this general mathematical representation can be greatly simplified by making appropriate assumptions about the relative unimportance of various physical effects, without compromising the fidelity of the solution with regards to the parameters of interest (i.e. altitude, coast time, etc.) For instance, if a rocket has a typical static stability margin such that it does not exhibit any obvious oscillations during its upward flight, then it is reasonable to assume that its rotational motion can be decoupled from its translational motion, thereby reducing the number of degrees of freedom by three. Specifically, any rigid-body oscillations of the rocket are assumed to have sufficiently small magnitudes and to occur sufficiently fast that their effects on the motion of the rocket's mass center are negligible. Another common assumption is that the rocket's upward trajectory is contained in a single plane, thereby allowing one translational degree of freedom to be ignored.

In the next section, the particular assumptions made in this analysis are presented and discussed. It should be pointed out that some of the simplifications are made primarily to allow closed-form solutions to the differential equations, thereby avoiding numerical integration.

Assumptions

The following specific assumptions are made in the performance analysis of a single-stage rocket:

1) The rocket is launched vertically and maintains a vertical trajectory through apogee. Thus the motion has only one (translational) degree of freedom.

2) The angle of attack of the rocket with respect to the incident airflow remains zero throughout the flight. This implies that the rocket does not oscillate, and that there is no crosswind or turbulence present. The aerodynamic effects are therefore limited to a drag force acting along the longitudinal axis of the rocket.

3) During the boost phase, the mass of the rocket remains constant at the average of its initial and burnout masses.

4) The thrust of the rocket motor is constant at its average value, which is obtained from the motor designation or by dividing the total impulse by the burn time. This is a potential limitation of the analytical approach when applied to advanced rockets using motors with high initial thrust levels followed by a lower thrust sustainer phase, in that using the average thrust value causes an underestimation of the initial velocity trend and therefore the drag force. However, for the purpose of predicting the peak altitude, this error could be approximately offset by a suitable "fudge factor" adjustment to the effective drag coefficient.

5) The drag coefficient is constant. This is probably the most serious limitation of this approach for advanced high power rockets that approach or exceed supersonic velocities, in that the abrupt increase in the drag coefficient in the transonic regime is simply not modeled, thereby allowing for optimistic performance predictions in these cases.

6) The atmospheric density and gravitational acceleration are constants specified by their values at the launch pad.

Boost Phase Solution

The boost phase of the rocket trajectory starts at the instant of launch (time $t = 0$) and ends at motor burnout ($t = t_b$), when the motor stops producing thrust. Based on the assumptions stated above, the differential equation governing this phase can be derived from Newton's Second Law of Motion:

$$m\frac{dv}{dt} = F - mg - D \tag{1}$$

where v is the vertical velocity of the rocket, F is the average thrust force, g is the acceleration due to gravity (9.80665 m/s²), and m is the average mass during this phase:

$$m = m_{empty} + m_{motor} - \tfrac{1}{2}m_{propellant} \tag{2}$$

Here, m_{empty} refers to the launch mass of the rocket minus the motor, m_{motor} is the initial mass of the motor, and $m_{propellant}$ is the propellant mass (obtainable from the manufacturer's specifications). In equation (1), D is the aerodynamic drag force, defined as the product of the dynamic pressure $\frac{1}{2}\rho v^2$ (where ρ is the atmospheric density), a reference area A (taken as the cross-sectional area at the maximum body diameter d_{max}), and the dimensionless drag coefficient C_D:

$$D = \tfrac{1}{2}\rho v^2 C_D A = kv^2 \tag{3}$$

For notational convenience, the constant k is introduced:

$$k = \tfrac{\pi}{8}\rho\, C_D\, d_{max}^2 \tag{4}$$

Upon substituting equations (3) and (4) into (1) and separating variables, both sides of the equation can be integrated from the instant of launch (when the velocity is zero) to some arbitrary velocity and time during the boost phase. (In the integrands, v and t have been replaced by dummy variables of integration).

$$\int_0^v \frac{m}{F - mg - kv^2}\,dv = \int_0^t d\tau \tag{5}$$

Evaluating these integrals yields a closed form expression for the velocity of the thrusting rocket as a function of time:

$$v_{boost}(t) = \sqrt{\frac{F-mg}{k}}\,\tanh\left(\frac{\sqrt{(F-mg)k}\;t}{m}\right) \tag{6}$$

Since the velocity is just the time derivative of the vertical displacement y of the rocket, equation (6) can itself be integrated with respect to time:

$$\int_0^y d\psi = \int_0^t \sqrt{\frac{F-mg}{k}}\,\tanh\left(\frac{\sqrt{(F-mg)k}\;t}{m}\right)d\tau \tag{7}$$

resulting in the altitude of the thrusting rocket as a function of time:

$$y_{boost}(t) = \frac{m}{k}\ln\left(\cosh\left[\frac{\sqrt{(F-mg)k}\;t}{m}\right]\right) \tag{8}$$

The burnout velocity v_b and the burnout altitude y_b can be obtained by substituting the motor burn time t_b into equations (6) and (8), respectively.

Coast Phase Solution

After the rocket motor burns its propellant to completion at time t_b, equation (1) is replaced by its counterpart for the coast phase of the trajectory:

$$m_b \frac{dv}{dt} = -m_b g - kv^2 \tag{9}$$

Note the absence of the thrust force F and the replacement of the mass by its burnout value m_b, where

$$m_b = m_{empty} + m_{motor} - m_{propellant} \tag{10}$$

Upon separating variables in equation (9), the following integrals can be constructed with lower limits of integration corresponding to the motor burnout conditions:

$$\int_{v_b}^{v} \frac{m_b}{m_b g + kv^2} \, dv = -\int_{t_b}^{t} d\tau \tag{11}$$

This yields the expression for the rocket coasting velocity as a function of elapsed time from launch:

$$v_{coast}(t) = \sqrt{\frac{m_b g}{k}} \tan\left(\sqrt{\frac{gk}{m_b}} (t_b - t) + \tan^{-1}\left[\sqrt{\frac{k}{m_b g}} v_b\right]\right) \tag{12}$$

As a check, note that the right-hand side of this expression reduces to the burnout velocity v_b if the time is set equal to the burn time t_b.

If the left-hand side of equation (12) is set to zero, corresponding to the rocket attaining zero velocity at apogee, then it can be solved for the coast time t_c, which is useful in selecting appropriate motor delay times:

$$t_c = \sqrt{\frac{m_b}{gk}} \tan^{-1}\left(\sqrt{\frac{k}{m_b g}} v_b\right) \tag{13}$$

The total elapsed time from launch to apogee is simply the sum of the motor burn time and the coast time:

$$t_{apogee} = t_b + t_c \tag{14}$$

Using equations (13) and (14), a simpler expression for the velocity during coast can be written as an alternative to equation (12):

$$v_{coast}(t) = \sqrt{\frac{m_b g}{k}} \tan\left(\sqrt{\frac{gk}{m_b}} (t_{apogee} - t)\right) \tag{15}$$

Integrating equation (15) with respect to time yields the altitude of the rocket during the coast phase as a function of the elapsed time from launch:

$$y_{coast}(t) = y_b + \frac{m_b}{k} \ln\left(\frac{\left|\cos\left[\sqrt{\frac{gk}{m_b}} (t_{apogee} - t)\right]\right|}{\left|\cos\left[\sqrt{\frac{gk}{m_b}} (t_{apogee} - t_b)\right]\right|}\right) \tag{16}$$

Setting $t = t_{apogee}$ in equation (16) gives the peak altitude y_{apogee} attained by the rocket, (assuming that the motor delay time is sufficiently long), which can then be simplified using equations (13) and (14):

$$y_{apogee} = y_b + \frac{m_b}{2k} \ln\left(\frac{k v_b^2}{m_b g} + 1\right) \quad (17)$$

If the expressions for the burnout velocity v_b and the burnout altitude y_b (from equations (6) and (8)) are substituted into (17), then the peak altitude can be written as a function solely of the input parameters:

$$y_{apogee} = \frac{m}{k} \ln\left(\cosh\left[\frac{\sqrt{(F-mg)k}\ t_b}{m}\right]\right) + \frac{m_b}{2k} \ln\left(\frac{(F-mg)}{m_b g}\left[\tanh\left\{\frac{\sqrt{(F-mg)k}\ t_b}{m}\right\}\right]^2 + 1\right) \quad (18)$$

Numerical Examples

To illustrate the use of these equations and to provide a check case for validation of any calculator/computer programs based on them, a specific numerical example is presented here. The test rocket used is the Hypersonic 2300, a high-performance kit manufactured by North Coast Rocketry. It has a maximum body diameter d_{max} = 0.0620 meter (2.44 inches), and my particular version has an "empty" mass m_{empty} = 0.680 kilogram (24.0 ounces), which is really its launch mass minus the mass of the motor, i.e. including the parachute, recovery wadding, payload, etc.

Before ever having flown my Hypersonic 2300, I estimated its drag coefficient to have a value of about 0.4, in order to obtain "ballpark" performance estimates. (This was a rather arbitrary choice, based on the fact that most reasonably well-finished model rockets have a drag coefficient in the range from 0.3 to 0.7. Ref. 4 provides a rigorous method for obtaining a more accurate estimate.) At the LDRS X Launch in August 1991, I had the opportunity to have this rocket tracked for altitude, which provided a data point for "tuning" my estimate of the drag coefficient, or at least the value that is consistent with the theoretical model presented here.

I flew the Hypersonic 2300 using an Aerotech/ISP I65-15 motor, and it was optically tracked to an altitude y_{apogee} = 3006 meters (9862 feet) with a reported tracking error of 1.2%. The specifications for this motor (as well as the Aerotech/ISP J125) are as follows:

Motor	F (Newtons)	t_b (sec)	m_{motor} (kg)	$m_{propellant}$ (kg)
I65	65	10.8	0.755	0.378
J125	125	10.0	1.192	0.7205

One additional parameter that must be input to this model is the air density at the launch site. The following formula corrects the standard sea-level density for the effects of the launch site altitude (based on an exponential curve-fit of the lower atmosphere) and the ambient temperature (based on the ideal gas law):

$$\rho(T,H) = 1.225\left(\frac{518.67}{459.67+T}\right)\exp\left(-\frac{H}{10243}\right) \quad \left(\text{kg}/\text{m}^3\right) \quad (19)$$

where the altitude H is in meters and the temperature T is in degrees Fahrenheit. Since the Black Rock Desert is at an altitude H = 1220 meters (4000 feet), and the temperature T was about 100° F (if not hotter!) on the day of the launch, the corrected density ρ is approximately 1.008 kg/m^3.

My method for determining the effective drag coefficient was to use equation (18) to plot the apogee altitude for a range of C_D values, holding all other parameters constant; see Figure 1. An approximate value of $C_D = 0.48$, corresponding to the tracked altitude of 3006 meters, was then read from the graph. When substituted into equation (4) with the other quantities stated above, this resulted in a value of $k = 0.000730$ kg/m.

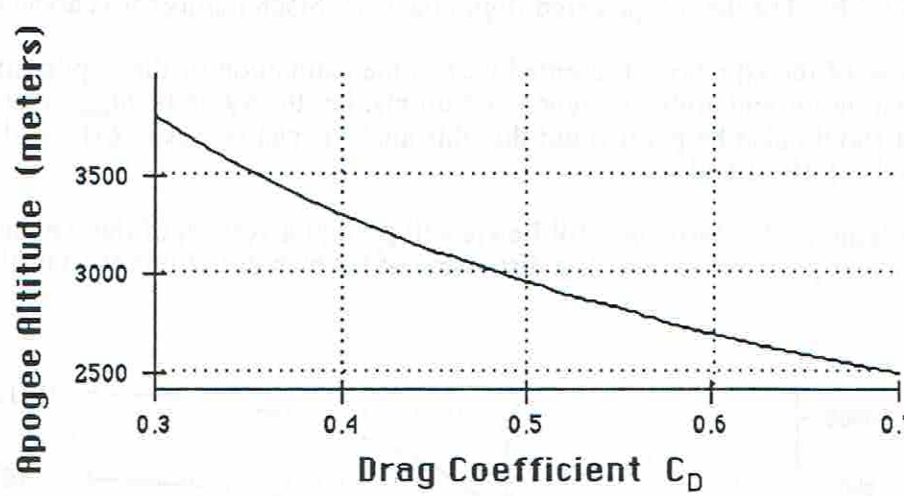

Figure 1: Peak altitude of the I65-powered Hypersonic 2300, as a function of the drag coefficient

The following table presents a summary of the various quantities computed as part of the flight performance calculations for the Hypersonic 2300, assuming all previously stated values and a drag coefficient of 0.48. Results are given not only for an I65 motor, but also for a J125, which I plan to fly at LDRS XI. Figure 2 presents the two altitude time histories (through apogee), computed using equation (8) for the boost phase ($t \le t_b$) and equation (16) for the coast phase ($t_b < t \le t_{apogee}$).

Motor	**I65**	**J125**
Average Boost Mass m (kg)	1.246	1.512
Burnout Mass m_b (kg)	1.057	1.152
Burnout Velocity v_b (m/s)	252	371
Burnout Altitude y_b (m)	1780	2500
Coast Time t_c (s)	13.7	15.8
Peak Altitude y_{apogee} (m)	3006	4305
(ft)	9862	14120

Discussion

A few comments can be made on the data in the above table. First, my observation of the parachute deployment on the I65-powered flight proved the choice of a 15-second time delay before ejection to be nearly perfect. Matching this specified delay to within 1.3 seconds of the predicted coast time of 13.7 seconds was quite adequate, given the errors associated with both the prediction and the time delay actually delivered, as well as the fact that the rocket is traveling slowly enough for safe parachute deployment within 1-2 seconds before or after apogee. Thus, a 15-second delay for the upcoming J125-powered flight should also work well.

Second, as an additional data point for comparison, it will be interesting to have this J125-powered flight tracked for altitude, especially since the predicted burnout velocity corresponds to a transonic Mach number of approximately 1.05, and there is no consideration made in this analysis for the accompanying increase in the drag coefficient. (The Mach number is defined as the ratio of the vehicle velocity to the ambient speed of sound, which is approximately 354 m/s for an ambient temperature of 100° F). For the I65-powered flight, the peak Mach number was about 0.71.

A further use of the equations presented here is the estimation of the "optimum mass" of the rocket for a given motor and ambient launch conditions, i.e. the value of m_{empty} that maximizes the peak altitude. It should also be pointed out that this analysis can be easily extended to multi-stage rockets, as shown in Refs. 1 and 3.

In the next issue of the *Aeronaut*, Bill Lewis will present a version of these equations coded up as a BASIC computer program, as well as a discussion of his own use of this analytical approach.

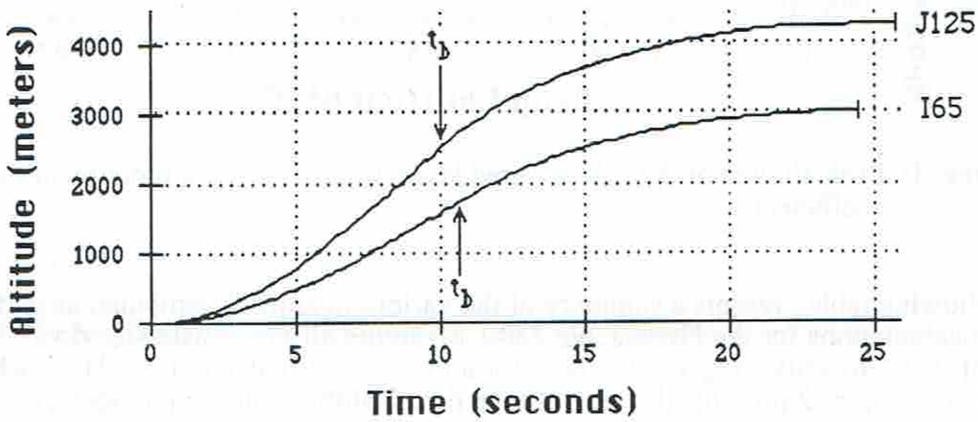

Figure 2: Altitude of the Hypersonic 2300 as a function of time from launch through apogee

References

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