Centuri

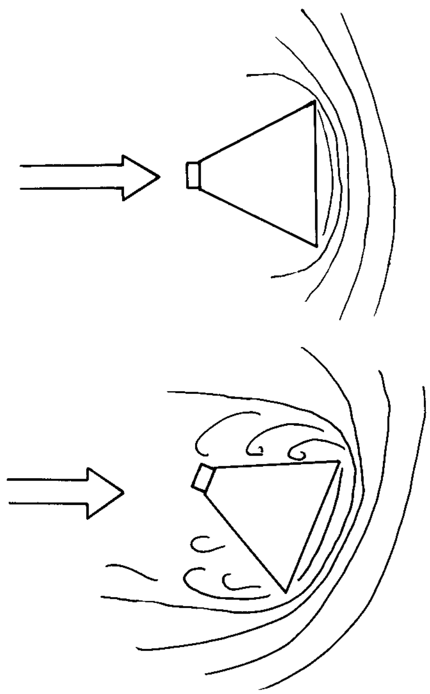
AEROSPACE WORKSHOP GUIDE

Centuri ENGINEERING COMPANY P.O. Box 1988 PHOENIX, ARIZONA 85001

QUESTIONS TO ASK YOUR STUDENTS

1. A cannon fires a ball into the air. Draw a cannon ball on the blackboard and ask your students if there is any lift acting on it and why.

2. The Apollo Capsule re-enters the Earth's atmosphere blunt end forward. Is there any way its pilots can give it "lift"?



They can – by giving it a slight angle of attack.

3. Would an airplane have any "lift" in space? Would it have any drag?

4. How far can you throw a ping-pong ball? What would happen if you threw the ball while standing on the moon? Why?

5. Using the AERO-LAB A as an example, find its center of gravity. Using Centuri's Technical Report TIR-33, locate its center of pressure. Should the rocket be stable? Why?

6. Launch the AERO-LAB A with a B4-2 Rocket Engine. Place a ping-pong ball in the chute compartment and time the flight from liftoff to the time the ping-pong ball touches the ground.

Replace the nose cone with the flat high-drag nose plug. Launch the rocket again with a B4-2 and time the flight from liftoff to ping-pong ball touchdown. Discuss with your class the meaning of the difference between the two performances. The power was the same in both flights. The weight was the same. What changed?

GRAVITY AND BALLISTIC FLIGHT

As we learned in our study of aerodynamics, the performance of a rocket is limited by the forces of drag and gravity. Definite relationships exist between the power, drag and weight of a rocket that enable us to predict a rocket's performance. The Centuri's Technical Information Report-100 presents this subject in detail. You will wish to consult that report before returning to this text.

TERMINAL VELOCITY: A body free falling in airless space is subject only to the force of gravity. As the body enters the atmosphere it becomes subject also to drag. Drag will tend to resist movement. The normal acceleration of free fall will be reduced by drag until the body stabilizes at some speed where drag and gravity balance. The object will continue to fall, of course, but at a uniform speed; at terminal velocity the object is no longer accelerating.

A ping-pong ball has a very low terminal velocity. (Ask your class why this should be so.) It has very little weight – only .04 ounce, but high drag. In free fall it will accelerate up to 30 feet per second. At this point it reaches terminal velocity and will fall at a uniform rate of 30'/sec. This is why you can use the ping-pong ball to measure altitude.

SAMPLE PROBLEM: A rocket was launched with a C6-5 engine. The burning time of a C6-5 is 1.7 seconds; the delay time is 5 seconds. A stopwatch recorded 20 seconds between liftoff and ping-pong touchdown. How high did the rocket go (assuming the ping-pong ball was ejected at apogee)?

Centuri's Technical Information Report-100 contains an examination on pages 50-51. You may wish to try some of these problems on your class.

EXPERIMENTS

1. Determine the weight and C_DA (Drag Form Factor) of your AERO-LAB A with a B6-4 engine in place. Using the graphs of Technical Information Report-100, determine the altitude the rocket will reach. Launch the AERO-LAB A and measure the altitude by triangulation or ping-pong method. How does it compare with your predicted altitude?

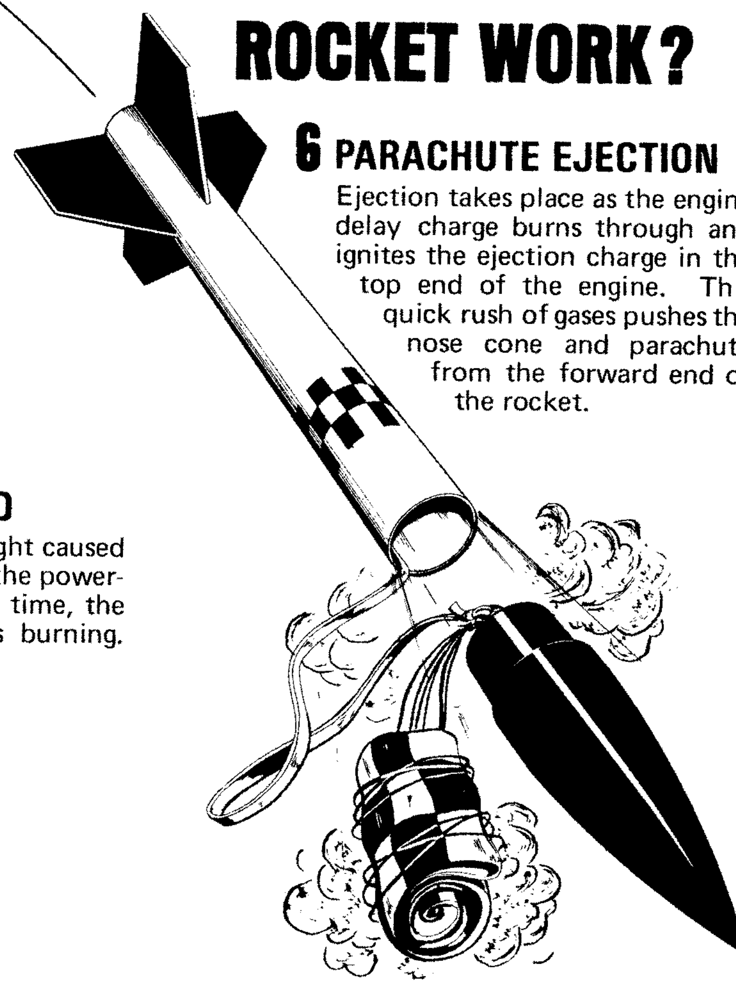
2. Fly the AERO-LAB again with a B6-4 engine with the flat <u>plug cone</u> and measure its altitude. Now with weight known and altitude known, what must the C_DA have been? What does this suggest about the value of streamlining?

3. How high would your Payloader Rocket go with a B6-4 engine?

4. A PROJECT: To prepare a graph illustrating the relative altitude performances of various engines: In red ink, trace your calculated altitudes with A5-2, B6-4, C6-5 and C6-0/C6-7 engines flying the AERO-LAB in (B) configuration. Use Technical Information Report-100. Then launch the Aero-Lab with the engines listed above and measure the altitude by triangulation or the ping-pong method. Record the results on the same graph with black ink. In each flight the total impulse was doubled. What happened to the altitude? Did it double also?

HOW DOES A MODEL ROCKET WORK?

5 APOGEE
Apogee as the rocket reaches peak altitude and begins descent.

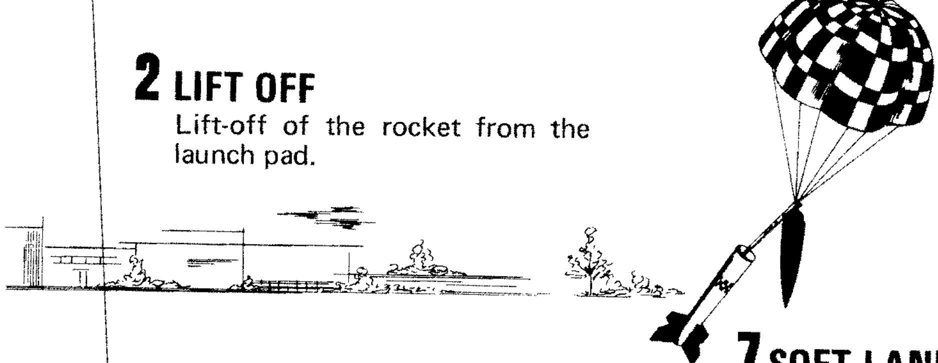


6 PARACHUTE EJECTION
Ejection takes place as the engine delay charge burns through and ignites the ejection charge in the top end of the engine. This quick rush of gases pushes the nose cone and parachute from the forward end of the rocket.

4 COASTING PERIOD
Coast period of the flight caused by thrust produced in the powered phase. During this time, the engine delay charge is burning.

3 BURNOUT
Burn out of the powered flight portion of the rocket engine.

2 LIFT OFF
Lift-off of the rocket from the launch pad.



7 SOFT LANDING
Slowly descending rocket lands safely, undamaged and ready for another thrilling flight.

1 IGNITION
Ignition of the rocket engine by remote electrical means.

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A BACKGROUND

Model rockets have been used in classrooms all over the country for several years. So far — especially in the younger grades — model rockets have been extraordinarily successful in generating excitement and enthusiasm among students and in illustrating, by their operation, the principles of rocketry and space flight. However, model rocketry has remained little more than a "happening" for teachers and students. Creative excitement is vital to the educational process; at the same time many educators have felt that the simple excitement did not yield enough to justify their investment of time and effort. Many educators have intuitively felt this and have avoided introducing model rocketry into their classrooms.

This has been a great loss to teachers and students alike. Model rockets, by virtue of their low cost, simplicity, and predictable propulsive power are uniquely suited for many experiments in the science that were heretofor impossible or impractical for a high school science classroom.

Recently it seems that Aerospace has lost much of its glamour. A decade ago the nation was clamoring for scientists and technicians. Students heeded the call, studied vigorously and became highly specialized professionals. Many of these professionals are now hunting for jobs and many of the new generation of young people are turning up their noses at aerospace and science in general. Much of this current abandonment of science arises from a gross popular misconception of what a real scientist is and does. Television has largely ruined the image of scientists. Our sponsors would have us believe that most of America's competant scientists spend their time developing detergents, floor wax, and deodorants. In the movies, scientists emerge as star-struck inventors, absent-minded tinkerers, or obedient wonder-makers who labor without conscience for tyrants. Only in the coverage of the space program do any scientists come across as halfway human and then, they have been so sandpapered and scrubbed by public relations enthusiasts as to be humorless and colorless.

Perhaps the first step in teaching science is to provide students with a more reasonable picture of what a scientist is. First of all, he is generally a normal person. Your students can, if they wish, become scientists. The scientist is brother to the philosopher: He seeks to understand himself and the world about him. Thus, his first and most important trait is a curiosity that never sleeps. Secondly, he is honest. This means he is aware of his shortcomings and prejudices and tries to control them as best he can. From this attempt the Scientific Method has arisen. The scientific method is a controlled inquiry: The scientist, from observation and reflection, has a hunch about something. Not wishing to jump to conclusions, he devises a test as honestly as he can to determine whether his hunch is correct. On the basis of his hunch, he predicts the outcome and waits. If the results of his test disprove his suspicions, he faces that fact; if the test demonstrates the accuracy of his prediction, he feels a special kind of pride, and proceeds to learn all he can about what he has discovered. Hypothesis, test definition, test execution, observation and conclusion — this is the scientific method. Intuition alone is much faster but wrong half the time. It has been the scientist, laboring alone and often in ridicule, who has given us the means to conquer disease, increase our food supply and leave the confines of the Earth's gravity. No one can say what the full impact of space travel will be. Your students will largely determine this: Stretch your imagination and try to visualize what your students may be doing twenty years from now. Young people are grasping for a meaningful role to shoot for. It is hard for them to motivate themselves if even their parents and teachers are unsure what use the world will have for them.

THE AEROSPACE WORKSHOP

Centuri's Aerospace Workshop has been designed for practical use in the classroom. Model rockets remain exciting and motivating for students. Now this excitement and motivation can be directed into the study of aerodynamics, gravity, terminal velocity, rocket principles and Newton's laws, combustion, rocket efficiency, staging and engine clustering, acceleration, and space biology. The test explains each topic in understandable language, offers examples and sample questions and then outlines experiments that can be performed in each area.

This publication is the preliminary text for the workshop. It will be further expanded and developed by the final publication date.

We at Centuri hope that this preview will interest you in the program and pursuade you of the important role model rockets can play in your science program.

THE PROGRAM HARDWARE

Centuri's Aerospace Workshop has been designed for your use. The text and experiments lend themselves to scientific methodology. We have tried to make the program as flexible as possible, comprehensible to the beginner in science, open ended enough to challenge the advanced teams of teachers and students.

WORKSHOP I — $20.00

Your basic equipment consists of the following:

- THE AERO-LAB A ROCKET
- "SERVO-LAUNCH" PAD
- TIR-30
- TIR-100
- 5 DESIGNERS HANDBOOKS
- WORKSHOP GUIDE
- SUPPLY OF ENGINES
- CHUTE WADDING

This is all the material you will need to conduct many of the more basic experiments in the Workshop Guide. Should you wish at a later date to replace items or augment your program, additional equipment will always be available at reasonable cost.

WORKSHOP II – $34.00

- AERO-LAB A ROCKET
- AERO-LAB B ROCKET
- ACCELEROMETER
- SERVO LAUNCHER
- TIR-30
- TIR-33
- TIR-100
- 20 DESIGNER'S HANDBOOKS
- WORKSHOP GUIDE
- SUPPLY OF ENGINES
- CHUTE WADDING

300 EXPERIMENT REPORT SHEETS – FILLED IN BY STUDENTS AFTER EACH EXPERIMENT

Workshop II is more advanced than Workshop I. A high performance Payloader rocket and an accelerometer module have been added. A mechanical accelerometer is provided as well. Additional experiments in acceleration and space biology are now possible.

WORKSHOP III – $45.00

- PAYLOADER II
- AERO-LAB A ROCKET
- AERO-LAB B ROCKET
- AERO-LAB C ROCKET
- SERVO LAUNCHER
- TIR-30
- TIR-33
- TIR-100
- TIR-52
- 25 DESIGNER'S HANDBOOKS
- WORKSHOP GUIDE
- ENGINE SUPPLY
- CHUTE WADDING
- WALL POSTER SET

300 EXPERIMENT REPORT SHEETS – FILLED IN BY STUDENTS AFTER EACH EXPERIMENT.

This is the complete program with the cluster engine mount and large payload capsule necessary for advanced experiments in rocket propulsion, drag, and space biology.

Additional material may be ordered at the following price schedule:

WALL POSTER SET	$ 3.00
CUT-AWAY ENGINE	$ 5.00
SKY TRACK	$24.00
2 SKY TRACKS	$44.50
VISIBLE ASTRO	$ 3.00
PAYLOADER II	$ 2.50
SERVO LAUNCHER	$ 5.50
LIA-77	$ 3.50
EFC-2 PANEL	$ 3.50
TIR-30	$ .75
TIR-33	$ 1.00
TIR-100	$ 1.00
DESIGNERS MANUAL	$ 1.00
AEROSPACE WORKSHOP TEXT	$ 4.00
CENTURI CATALOG	$ .25

Prices and specifications may be subject to change.

Instructions for the assembly and operation of your rockets and launchers accompany each piece of equipment.

AERO-LAB ROCKET SYSTEM

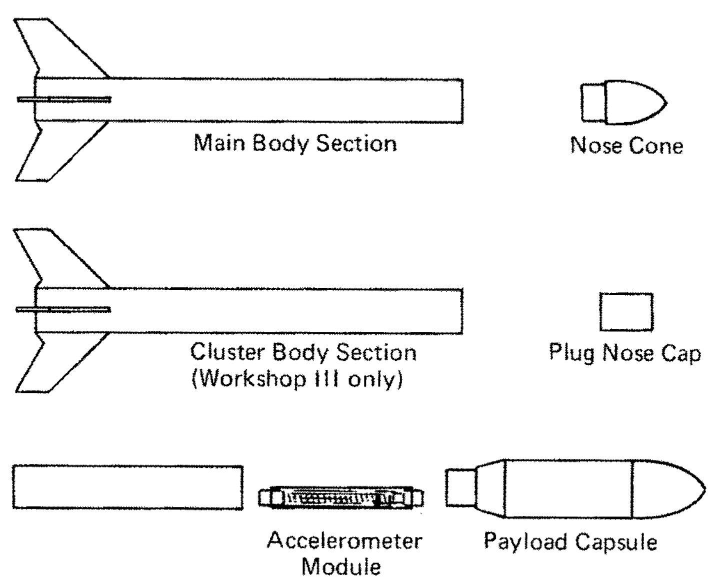
AERO-LAB ROCKET COMPONENTS:

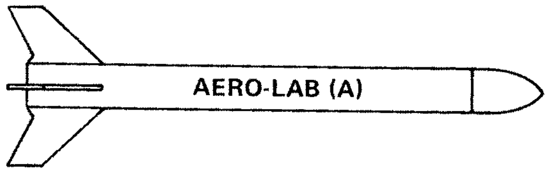
MAIN BODY SECTION & CONES	$ 2.00
CLUSTER BODY SECTION	$ 2.25
ACCELEROMETER MODULE	$ 4.00
PAYLOAD CAPSULE	$ 2.00

Assemble your rockets according to the directions provided in each kit.

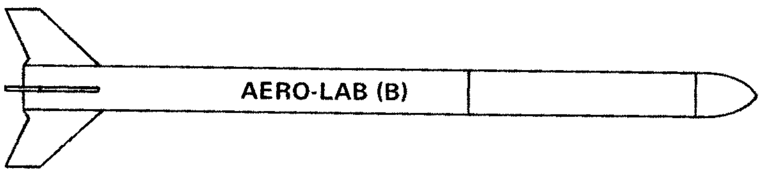
If you are using the Workshop I, your rocket is a Centurion. It will correspond to the Aero-Lab (A) described below.

AERO-LAB ROCKET SYSTEM COMPONENTS:

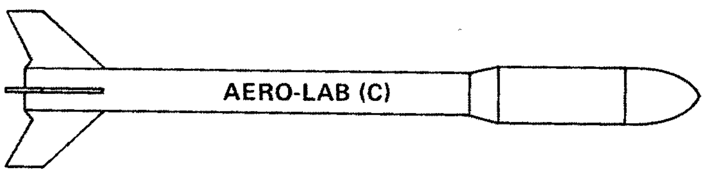




The AERO-LAB (A) is the main body section and nose cone (or plug nose cap).



The AERO-LAB (B) is composed of either of the single engine or cluster body tube sections topped by the accelerometer module and nose cone.



The AERO-LAB (C) is composed of either of the single engine or cluster body tube sections topped by the payload capsule.

The rocket instruction sheets will provide you with all the instructions you need to prepare and operate these rockets.

ALTITUDE DETERMINATION

The Centuri Sky Track is a carefully engineered theodolite for measuring angles of azimuth and elevation. Altitudes can be determined by triangulation from graphs and tables that come with the instrument. The Sky Track is durable as well as functional and will serve many purposes for years of use.

An additional system for altitude determination exists which is quite simple. It will work for any rocket big enough to carry a ping-pong ball in its parachute compartment. When the parachute is ejected the ping-pong ball is released to free fall. Ping-pong balls fall at a uniform rate of 30'/sec. (see terminal velocity). The altitude of the rocket at ejection can be determined with a stopwatch, counting seconds from ejection to the landing of the ball. As unscientific as this sounds, the system yields surprisingly good results. For improved visibility the ping-pong ball can be patterned with a magic marker, half white, half black. The ball then flashes while it drops. Fluorescent orange balls are available also for improved visibility. The time can also be taken from liftoff and the following formula applied.

$$\begin{array}{c}\text{Total seconds} - (\text{burn} + \text{delay time}) \\ \times\ 30 \\ \hline \text{Altitude in feet}\end{array}$$

AERODYNAMICS

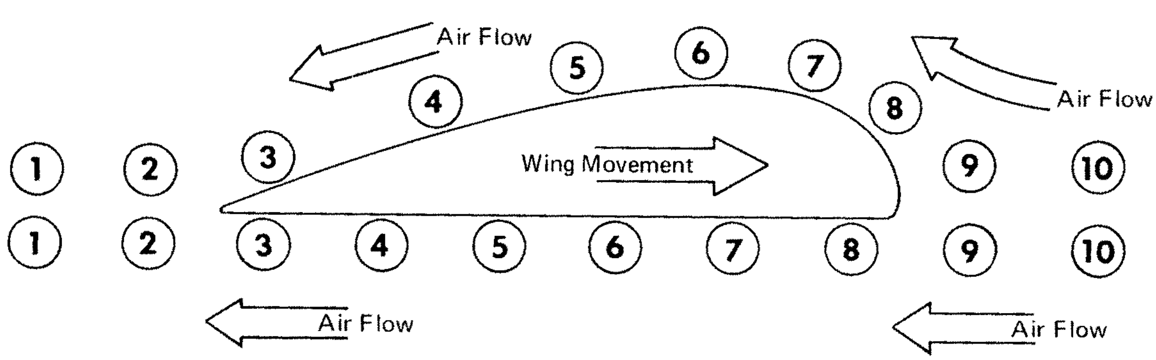
Aerodynamics is the study of the movement of air and other gaseous fluids over solid bodies and the forces acting on solid bodies in motion through the air.

Model rockets are solid bodies moving through the atmosphere. Since their area and weight can be found and their motive power determined (by selecting an engine of a known power) model rockets become an ideal subject for experiments in aerodynamics.

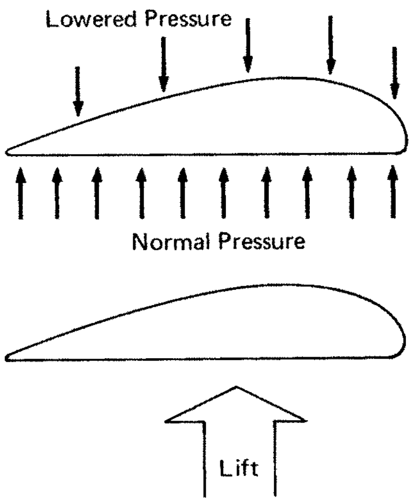
The aerodynamic fundamentals covered in this text are: Lift, drag, and stability.

LIFT: Lift is a phenomenon which occurs when an irregularly shaped body moves through the air or when a symmetrical shape moves through the air at an angle of attack. Children in a moving automobile often play by holding their hands out the window in the airstream. They soon find that by making a "wing" with their palms flat and angling their palm to the wind, they can make their hand swoop up and down. They are creating lift.

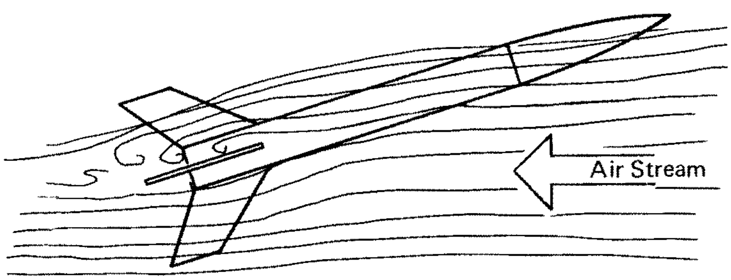
Imagine two columns of molecules flowing along like two lines of soldiers marching side by side. These two lines meet an obstruction – in this case the wing of an airplane. We'll number our molecules in each line one to ten. The line of molecules under the wing has an unbroken path. Progress is smooth; the interval from molecule to molecule is unbroken. However, the top line of molecules has to detour over the rounded top. In order to meet their matching molecule traveling along under the wing, they must "double time" and flow faster. In the process, the line "thins out" – the interval between molecules is greater. At the other end of the wing, the molecules rejoin their comrades and flow along evenly again.



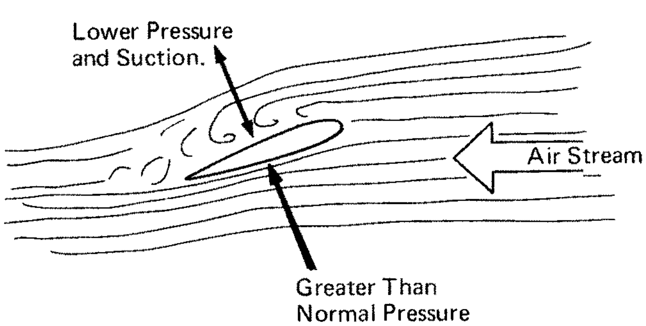
All gasses are under some pressure or other. We know that the less dense or lighter the gas, the less pressure it exerts. Therefore, when our top stream of air molecules "thinned out" while flowing over the wing it exerted less pressure on the wing than the stream of molecules on the bottom of the wing (which remained at normal density). This imbalance of pressures; low pressure atop the wing, normal pressure below the wing, tends to "lift" the wing or move it into the area of low pressure. Naturally, the faster the air is moving over the wing the greater the lift produced.



Lift not only makes airplanes fly by supporting their weight while their engines thrust them through the air, it also helps rockets fly stably through the air by acting on their tail fins. When a rocket which has been flying on a true path is diverted from its course, it is presented to the wind at an angle (called the angle of attack).



This causes the air to flow over the tail fins unevenly. The bottom of the fin receives the direct pressure of the airstream; the upper surface is out of the airstream. Air curls over the top of the fin turbulently; a suction is created as the airstream pulls down to join the stream flowing under the fin. Again we have an imbalance of pressures; greater than normal pressure under the fin, lower than normal above the fin:



Lift is again produced – lift that will tend to return the rocket to zero angle of attack. When we discuss stability we will determine how lift can best be used to resist any forces that might deflect a rocket from its intended course.

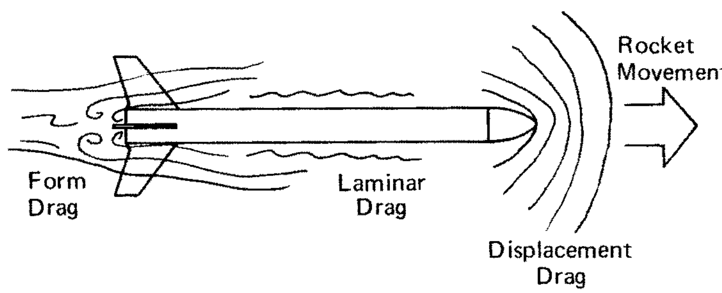
DRAG: Drag is more commonly known as "resistance" or "wind resistance". It is a form of friction. When a rocket climbs into the sky it is constantly encountering air molecules in its path and pushing them aside. This takes energy. Once pushed aside, these air molecules drag along the sides of the rocket, using up more of the rocket's power. Finally, as the airstream rejoins behind the rocket, turbulence and suction are produced. The resulting low pressure behind the rocket adds further to the drag.

We can identify three kinds of drag:

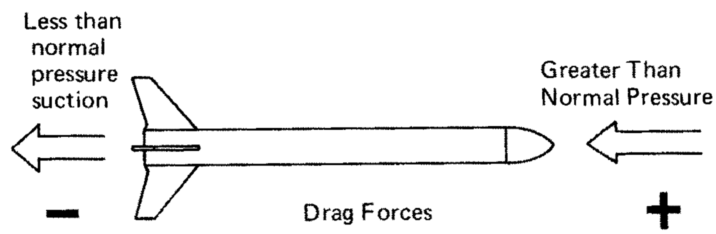
1. "DISPLACEMENT DRAG"
when the nose cone displaces air in its path;

2. "LAMINAR DRAG"
or friction of the rocket along its sides as it slips through the air and

3. "FORM DRAG"
at the tail of the rocket as the air closes around the after end with turbulence and suction.



These forces tend to act in a direction opposite to the rocket's movement. Along with gravity, drag is the other force which a rocket must overcome when operating within the Earth's atmosphere.



STABILITY: Your Technical Information Report-30 covers the fundamentals of stability thoroughly.

We have now covered the principles of aerodynamics, lift, drag and stability. These principles are very important in understanding how airplanes and rockets fly and in predicting what a particular rocket or airplane will do when flown.

5. A PROJECT: Centuri offers a flashing light payload. Fly the Payloader Rocket at night with a B14 engine. Photograph the flight with tri-x film, leaving the shutter open from a distance of 300 feet. The rocket will describe a ballistic arc. The effects of gravity will become evident from the spacing of the light impressions. The photograph will reveal an arc of dots, spaced far apart near the earth then crowding closer together as the rocket shows near apogee and covers less ground per flash interval.

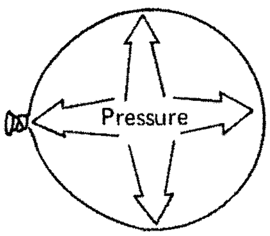
ROCKET PRINCIPLES AND NEWTON'S LAWS

In the eighteenth century, Sir Isaac Newton formulated the fundamental laws of motion. Among these, the laws most famous and most relevant to rocket flight are the following:

1. For every action there is a corresponding equal but opposite reaction.

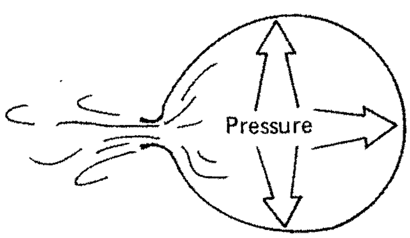
2. A body at rest tends to remain at rest. A body in motion tends to remain in motion at a given speed in a straight line unless acted upon by an outside force.

Blow up a balloon with air and release it. What makes it fly? As long as your fingers held the end closed the air was imprisoned inside the balloon – air under pressure pushing against the sides.



Equal Pressure on All Sides

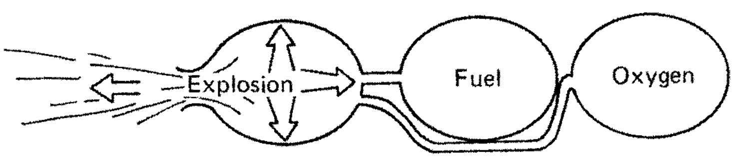
Then when you released the end, you allowed gas to escape. With one end open, the pressures inside the balloon were unbalanced. The positive pressure on the forward end of the balloon pushed the balloon along – driving it in the opposite direction of the escaping gas.



Unequal Pressure

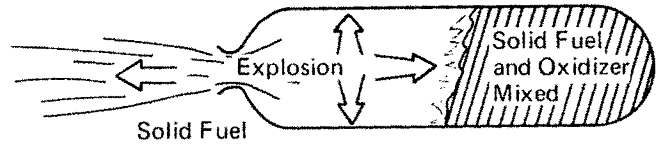
Balloon Moves in Direction Opposite Escaping Gas

In a liquid fuel rocket, the fuel and the oxidizer are mixed in a chamber and ignited. They explode, creating a rush of expanding gas. The gas rushes out of the chamber – like our balloon – and the reaction drives the rocket forward. The explosion creates much greater pressures than we can put in a balloon and so the thrust is much more powerful.



Liquid Fuel Rocket

In a solid fuel rocket, the fuel and oxidizer are mixed together in a solid form. When ignited the mixture begins a continuous explosion until the mixture is consumed.



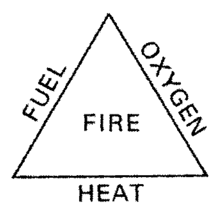
Solid Fuel Rocket

In a solid fuel rocket, the walls of the chamber form the tank for the propellant mixture. As you can see, solid fuel rockets are much simpler than liquid fuel rockets, which is why model rockets use solid fuels.

COMBUSTION

Perhaps we should examine combustion or burning. (If your class is sufficiently advanced this discussion will have been more rigorously held in your chemistry class.)

Three things are necessary to have a fire: Fuel, heat, and oxygen. These can be easily remembered in the fire triangle:



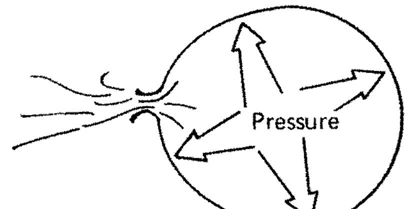
You can see why, if you want to put a fire out, you can throw water on it – removing its heat; or spraying it with a carbon dioxide fire extinguisher – which smothers it by taking away its oxygen.

A rocket can fly in space because it carries its own oxygen along with it as well as its fuel. As far as we know rocket propulsion is the only way we can travel in space.

ROCKET ENGINE EFFICIENCY

Let us return to our "balloon rocket" again. How could we make it fly differently? Suppose we block part of the nozzle so less gas escapes. We get thrust for a longer time, but the strength of the thrust has dropped. Try this with your class. Ask why this is so.

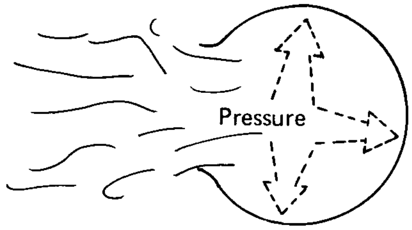
What you have done by constricting the nozzle is that you have increased the pressure on the nozzle end. There is less difference now between the pressures on the rear and forward end – hence less thrust.



Your thrusting time increased, though. Sometimes this is desirable. However, on your balloon it doesn't work.

What if you opened the nozzle up much larger than normal? If the little nozzle doesn't help maybe a bigger one will. Sample your class for opinions on whether this will result in an improvement.

The gas rushes out instantly, the balloon leaps forward for a second and collapses, empty. What happened?



The huge opening allowed the pressure in the balloon to escape too easily. As a result the pressure was certainly unbalanced, but very weak. There must be confinement to be pressure and there wasn't enough. The gasses leaving the open end were moving very slowly with such low pressure and so there was little reaction and little thrust.

What does this demonstrate? There must be some optimum shape for a rocket balloon (and for a real rocket motor) at which the pressures generated inside are used to the greatest advantage. Model rocket engines have been designed for optimum performance at the speeds they travel. Perhaps some of your pupils may wish to become capable of designing the rocket engines of the future to operate at their greatest capacity. To do this they must become capable of realizing their greatest capacities.

STAGING & CLUSTERING

These experiments will require some advanced math and a bit of advanced equipment. If your class is not ready for this section you may wish to omit it or omit some of the "heavier" material in it.

When a rocket designer needs more power he often designs a more powerful motor. Often this becomes a difficult and expensive proposition. Two techniques exist which enable the rocket designer to use smaller engines in combinations to "build up" the power he wants:

STAGING: Staging is basically putting two rockets together, one atop the other. The first rocket (called a stage) carries the pair into the air. When its engine has burned out, the second stage fires, carrying the rocket still higher. The first stage falls away when the second stage fires; it tumbles back to Earth by itself. Suppose each of two identical stages could reach 150 miles per hour if fired by itself and that it would be 1,000 feet in the air when its engine stopped burning. Now we put one on top of the other. The first stage is carrying a load (the second stage). This will reduce its performance compared to what it could do alone. Let's say it will only reach 100 miles per hour and 600 feet at burnout. Now the second stage fires adding its full 150 miles per hour and 1,000 feet of burning altitude to what the first rocket achieved. When it burns out it will be traveling at 250 miles per hour and will burn out 1600 feet.

Naturally, it will coast for a while. Perhaps at 150 miles per hour it would have coasted one thousand feet but, thanks to the 100 miles per hour contributed by the booster, it is doing 250 miles per hour. It may coast up 1,800 feet. Our rocket burned out at 1,600 feet and coasted another 1,800 feet. Altogether it will rise 3,400 feet above the Earth. The second stage rocket fired by itself would have reached 2,000 feet had it been launched by itself.

You can see why staging is an attractive system. Suppose we added a third stage. Let us visualize this as a new booster added under the previous two stage rocket. It, too, uses the same engine. This booster must lift two additional stages. It may only reach 50 miles per hour when it burns out at, say, 350 feet. This means the third stage has contributed only 350 feet to our burnout total and 50 miles per hour to our total speed. The third stage will now burn out at 300 miles per hour. If it coasted 1,800 feet before, it may coast 2,100 feet now. Our total: Burn out altitude – 1,950 feet, coast altitude – 2,100 feet, is 4,050 feet. By adding a stage we only got 750 feet.

VB = BURNOUT VELOCITY

SB = BURNOUT ALTITUDE

SINGLE STAGE PERFORMANCE

	VB	SB	COAST	TOTAL
STAGE III ALONE	150 mph	1,000′	1,000′	2,000′

TWO STAGE PERFORMANCE

	VB	SB	COAST	TOTAL
STAGE III	150 mph	1,000′	1,800′	
STAGE II	100 mph	600′		
TOTALS	250 mph	1,600′	1,800′	3,400′

ALTITUDE GAINED BY ADDING THIS STAGE: 1,400′

THREE STAGE PERFORMANCE

	VB	SB	COAST	TOTAL
STAGE III	150 mph	1,000′	2,100′	
STAGE II	100 mph	600′		
STAGE I	50 mph	350′		
TOTALS	300 mph	2,050′	2,100′	4,150′

ALTITUDE GAINED BY ADDING THIS STAGE: 750′

These three graphs illustrate that while staging continues to improve performance, the improvement in performance it offers diminishes in proportion to the number of stages added. This would be dramatically changed if the booster stages added were increased in power to better carry their loads.

CLUSTERING: In clustering lies the potential to increase the brute force necessary to lift large and sophisticated rockets. Clustering is the operation of several rocket engines at the same time. Our total thrust is the accumulated force of all the engines in the cluster.

Suppose we fly four identical rockets at the same time. Each rocket goes up 500 feet. If we tie all these rockets together, the bundle of them will also fly 500 feet. Where is the advantage then?

Suppose we decide that instead of using four body tubes and four nose cones, we will use one larger tube and cone. Likewise, we don't need four parachutes; one larger one will do. At the bottom of the rocket we add a mount for four engines. Suppose each of our four smaller rockets had four fins; all four of them had sixteen fins. Our clustered rocket doesn't need sixteen fins to fly properly; four fins, each larger than the fins on the single engined rocket, will be sufficient. Our new clustered rocket will have less drag than a bundle of four smaller rockets. The air will flow smoothly around the single hull, there will be less turbulence with only four fins. In addition, we have saved weight by removing many components we no longer need. We can add payload to the cluster rocket in place of the unnecessary parts. We end up with a large rocket with the ability to lift weights as high as one of the smaller rockets could have gone by itself. Now you can see the advantage of clustering – clustering will lift weight.

The rockets used in America's space program combine the staging and clustering principles to great effect. Heavy clustered boosters lift the rockets into the air and then upper stages, (often clusters themselves) continue to add speed and altitude until the rockets are in Earth orbit or heading off into deep space – perhaps to the moon. Centuri's Technical Information Report-100 offers a thorough treatment of clustering on pages 9 and 10.

The main difficulty in clustering is igniting all your engines at once. In model rocketry this requires more electrical power than your LIA-65 launcher can provide. If you wish to experiment with clustering you will need a pad unit such as the LIA-77 launcher and the EFC-2 control panel featured in the Centuri catalog. One of your students may also have a launcher you can cluster from. In any event, the LIA-65 launcher was designed to handle single and multi-staged rockets but not clusters. Centuri's Technical Report, TIR-52, reviews the principles and techniques necessary for successful clustering.

EXPERIMENTS

1. Using Centuri's Technical Information Report, TIR-100, compute the performance of the AERO-LAB (C) using two B6-4 engines. Compare the prediction with the measurement of a flight test.

2. Fly the AERO-LAB in two staged form (configuration C) using a B6-0 to a B6-6 engine combination. How do the performances of 1 and 2 compare? Discuss.

3. Add a one ounce lump of clay to the payload compartment of the Aero-Lab and repeat experiments 1 and 2. Compare the results and discuss.

ACCELERATION

Acceleration is the rate of change of velocity and can be expressed either in terms of feet per second (or any unit of speed divided by time) or in terms of multiples of the acceleration of gravity (or Gs) at 32 feet per second. The effect of acceleration is measured in multiples of gravity or G forces.

A falling stone accelerates at one G until it reaches terminal velocity. A rocket may accelerate on its upward flight thirty times faster than a stone drops. The components of the rocket – and any living creatures inside – would experience 30 Gs or thirty times their normal weight. This phenomenum follows the second Newtonian law of motion mentioned at the beginning of this section concerning momentum and inertia.

We have all experienced that sinking feeling in the stomach when we go up on a fast elevator. Take a set of bathroom scales on a fast elevator with you and as the elevator starts up notice what your weight increase went up to. Divide the increase into your normal weight to find the additional G forces. Normal gravity is 1 G; you may have experienced 1-1/3 Gs.

An accelerometer is an instrument that measures and records changes in experienced weight due to G forces. It works much like a spring loaded scales. Study the report and the diagram accompanying the Centuri mechanical accelerometer. As the effective weight of the slide increases under acceleration, the springs is compressed under the load. A light paper slide is pushed down the scale to record the maximum acceleration. The slide is so light it is uneffected by the acceleration itself. Simple friction holds it in place.

We can determine the G forces on a rocket at any point during thrusting by making a simple ratio of the rocket's weight to its thrust.

$$\frac{\text{Thrust}}{\text{Weight}} = \text{G's}$$

1. Compute the G forces at liftoff for an AERO-LAB B with a B4-2 engine. Launch and measure altitude and G forces. Repeat the proceedure with a B6-4 and a B14-5. Does any pattern develop from this? Compare the thrust curves of each engine in the Technical Information Report, TIR-100. Does one engine appear to have an optimum performance? Discuss in light of our earlier balloon rocket discussion.

2. Does staging produce more G forces than the upper stage would produce alone? Fly the AERO-LAB B with a B6-0 to a B6-4 engine and record G forces. Compare with the G forces recorded on the flight with a single B6-4 in the previous experiment. Obviously the burnout speed of the two stage was higher but its <u>acceleration</u> was the same.

3. Compare the acceleration of the single B6-4 flight with a cluster of two B6-6 engines in the AERO-LAB B.

In the next section we will discuss the effects of acceleration on living organisms.

SPACE BIOLOGY

One of the most fascinating aspects of the space age is the study of rocket flight and zero gravity on animals and man.

Model rocketeers often find it an exciting experience at some point in their association with the activity to fit a mouse in the nose of their rockets and fire the animal into the air. The scientific interest of such an experiment does not usually justify the terror and discomfort that is the mouse's share in this achievement. A few advanced groups can record the mouse's respiration and heartbeat and telemeter this data to Earth during the flight. For these few groups the end may justify the means; otherwise there is little that can be determined by a mouse flight. In the post-mortem the mouse is found to be:

(A) DEAD

(B) ALIVE

In the former case it is dropped by the tail into the trash; in the latter the reporters are called in; the mouse becomes a hero and, if unmolested, is permitted to live out the rest of his days in peace. This is not science.

This is not to say that model rockets have nothing to offer to the study of space biology. Model rockets are capable of accelerating to over 60 Gs. This is a formidable shock and the results can be quite interesting with a suitable subject.

What does acceleration do to a living creature anyway? We remember how our stomachs feel in a rising elevator. Not only are our bodies subject to G forces, but our organs as well. The rising floor of the elevator bears up our feet. If our knees hold, our stomachs and lungs have yet to be pursuaded to come along. They try to remain at rest. They sag, trying to stay behind until they too are moving along with the rest of our body. This same process is repeated with all our organs, the blood in our veins and even the change in our pockets. Should the acceleration be too great our bodies might not be able to stand the strain; our blood vessels might burst and our organs tear free from their connective tissues. Our blood would tend to collect in our legs starving the brain. We would lose consciousness.

Scientists have found ways to relieve the effects of acceleration to an extent.

First of all, the displacement of organs and blood is less severe if we are lying down with the acceleration at our back.

Pressure suits have been developed which sense the deformation of our bodies under acceleration and squeeze back to hold us in shape and our organs in place. These are the familiar suits worn by pilots.

Acceleration is still a problem and manned rockets must not be designed to accelerate much faster than ten or eleven Gs.

Some common biological specimens can be observed intimately and thus make better subjects for acceleration studies than mice.

Insects are not especially useful. Ask your class to speculate why. Insects usually have hard exo skeletons. These act as pressure suits.

Flatworms make better subjects. They are semitransparent and can be examined in detail. Hydra make good subjects, too. They curl up when disturbed and usually, the more bothered they are, the longer they will remain retracted.

Simple one-celled organisms are transparent and will thus reveal clearly any damaging effects of high acceleration.

EXPERIMENTS

All these experiments except the last one require the use of the Payloader Rocket with B14-5 engines.

1. Launch a flatworm in a small watertight capsule during its division process and observe effects.

Does it survive?

Does the division process take longer than it does normally?

Are future generations of flatworms normal?

2. Launch and observe Hydra in a water capsule.

3. Launch and observe one-celled organisms.

Are there evidences of internal cell damage?

Is cell division effected?

Are future generations normal?

4. Use the AERO-LAB C for this experiment powered by a cluster of two C6-3 engines.

(A) Procure an incubated, fertilized hen's egg.

(B) Launch in warm padded capsule and recover.

(C) Continue incubation.

Does the egg hatch? Is the chick normal?

Note: You may wish to "rehearse" with a store bought egg the first time.

All the specimens but the egg were submerged in water. Does water have a protective effect? Why?

You will undoubtedly be able to think of more experiments along this line. The importance lies as much in the method and care in which the experiments are carried out as in their respective results.

NOTES