

The Adventures of
ARCHIBALD HIGGINS

FLIGHT OF FANCY

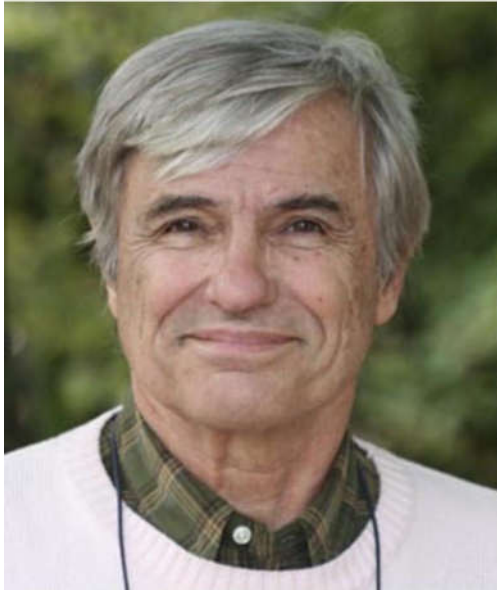


Jean-Pierre Petit

Translated by Ian Stewart

Knowledge without Borders

Non-profit-making association created in 2005 and managed by two French scientists. Aim: to disseminate scientific knowledge using the band drawn through free downloadable PDFs. In 2020: 565 translations in 40 languages had thus been achieved. With more than 500,000 downloads.



Jean-Pierre Petit



Gilles d'Agostini

The association is totally voluntary. The money donated entirely to the translators.

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<http://www.savoir-sans-frontieres.com>



The Association Knowledge without Borders, founded and chaired by Professor Jean-Pierre Petit, astrophysicist, aims at spreading scientific and technical knowledge in as many countries as possible and in as many languages as possible. To this end, all his popular scientific works, which cover a period of thirty years, and more particularly the illustrated albums he has created, are now freely accessible. Anyone is now free to duplicate the present file, either in digital form or in the form of printed copies and circulate these copies to libraries, within the context of schools or universities or associations whose aims would be the same as the association, provided that they do not derive any profit from this circulation and that they do not have any political, sectarian or confessional connotations. These pdf files may also be put on line in the computer networks of school and university libraries.



Jean-Pierre Petit intends to create numerous other works which will be accessible to a larger audience. Even illiterate people will be able to read them because the written parts will “speak” when the readers click on them. Thus it will be possible to use these works to support literacy schemes. Other albums will be “bilingual” in so far as it will be possible to switch from one language to another selected language with a mere click. Hence another tool made available to develop language skills.

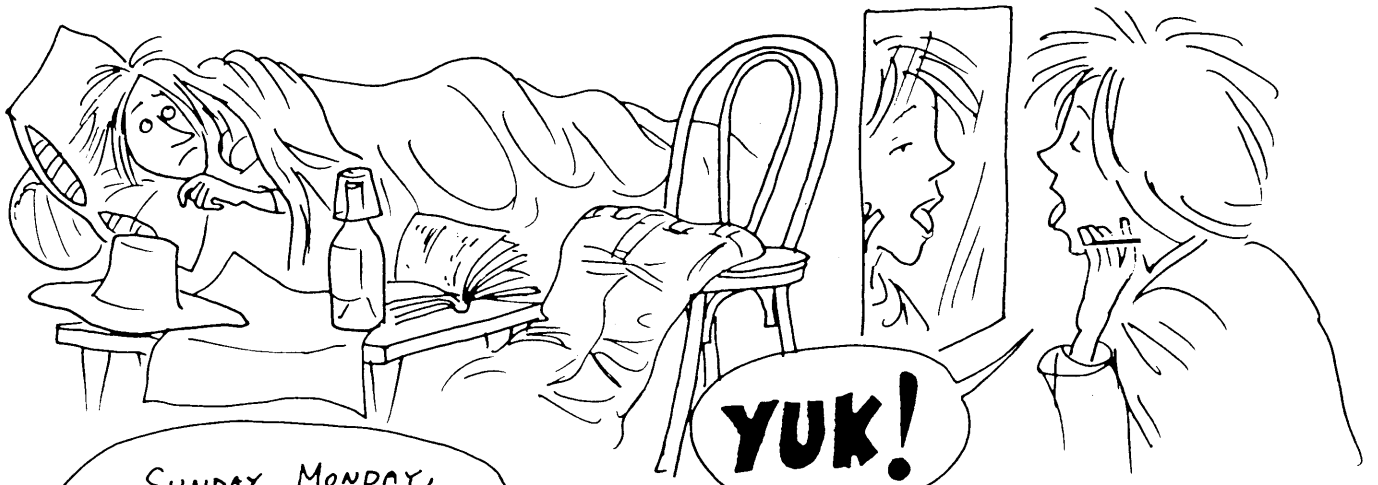
Jean-Pierre Petit was born in 1937. He made his career in French research. He worked as a plasma physicist, he directed a computer science centre, he has created softwares, he has published hundreds of articles in scientific magazines, dealing with subjects ranging from fluid mechanics to theoretical cosmology. He has published about thirty books which have been translated in numerous languages.

The association can be contacted on the following internet site:

<http://savoir-sans-frontieres.com>

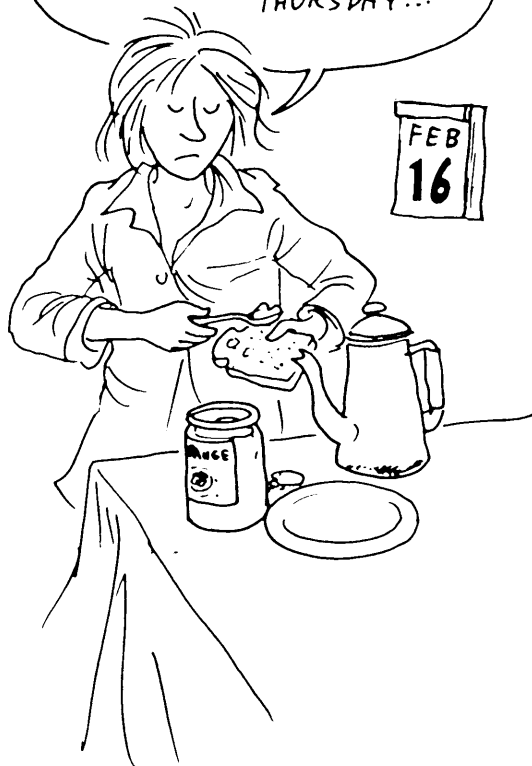
PROLOGUE:

ONE MORNING, ARCHIBALD HIGGINS WOKE UP IN A ROTTEN MOOD...



SUNDAY, MONDAY,
TUESDAY, WEDNESDAY,
THURSDAY...

FEB
16



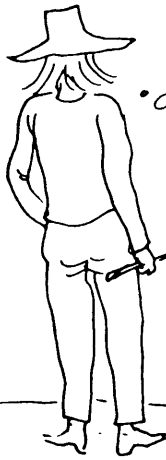
... FRIDAY, SATURDAY,
SUNDAY. AND THEN IT
STARTS ALL OVER
AGAIN. BORING,
ISN'T IT?



I'M NOT SURPRISED.
THE BUTTERED SIDE, NO
DOUBT.



ARCHIE FELT SAD AND EMPTY. EVEN THE EARTH WAS FLAT. THE DAYS TRICKLED PAST LIKE RAINDROPS DOWN A WINDOW-PANE...



MAX. WHERE'S MAX?

HE'S UP THERE, THE LUCKY FELLOW...



MAX!
I WANT TO **FLY**
TOO **!**



YOU? FLY?
GOOD HEAVENS!

MAX - YOU'VE **GOT** TO
TEACH ME TO FLY. JUST A LITTLE
BIT. IT'S GETTING ME DOWN,
STUCK ON THE GROUND
LIKE THIS.



LOOK - I CAN LIFT **ONE** FOOT. IF I
LIFT THE OTHER ONE QUICKLY ENOUGH,
MAYBE I CAN...

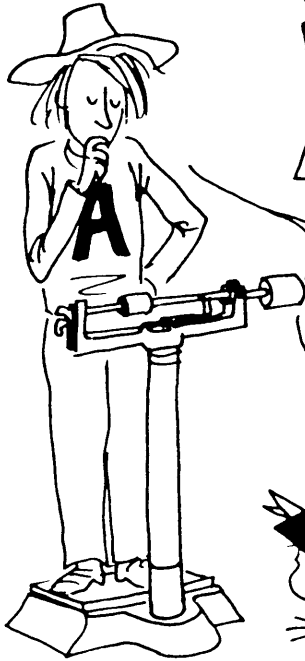


IT MUST HAVE BEEN
THE WEIGHT OF ALL THAT
AIR, PUSHING ME BACK
DOWN AGAIN.



QUITE THE CONTRARY, OLD BOY! ACCORDING TO
ARCHIMEDES' PRINCIPLE, THE AIR PRESSURE ACTUALLY
REDUCES YOUR WEIGHT BY 80 GRAMS.

ONCE UPON A TIME THERE WAS A MAN CALLED ARCHIMEDES



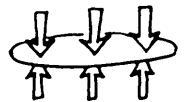
YOU MEAN TO TELL ME THAT WHEN I WEIGH MYSELF, THE MACHINE DOESN'T GIVE MY TRUE WEIGHT — BECAUSE OF **AIR PRESSURE** ?



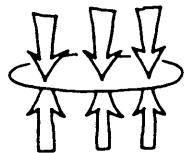
PRECISELY. YOU ACTUALLY WEIGH 80 GRAMS MORE.



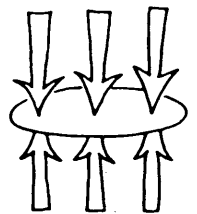
HMM... ARCHIMEDES' PRINCIPLE. I'VE HEARD THE **WORDS** OFTEN ENOUGH— BUT WHAT IS IT REALLY ?

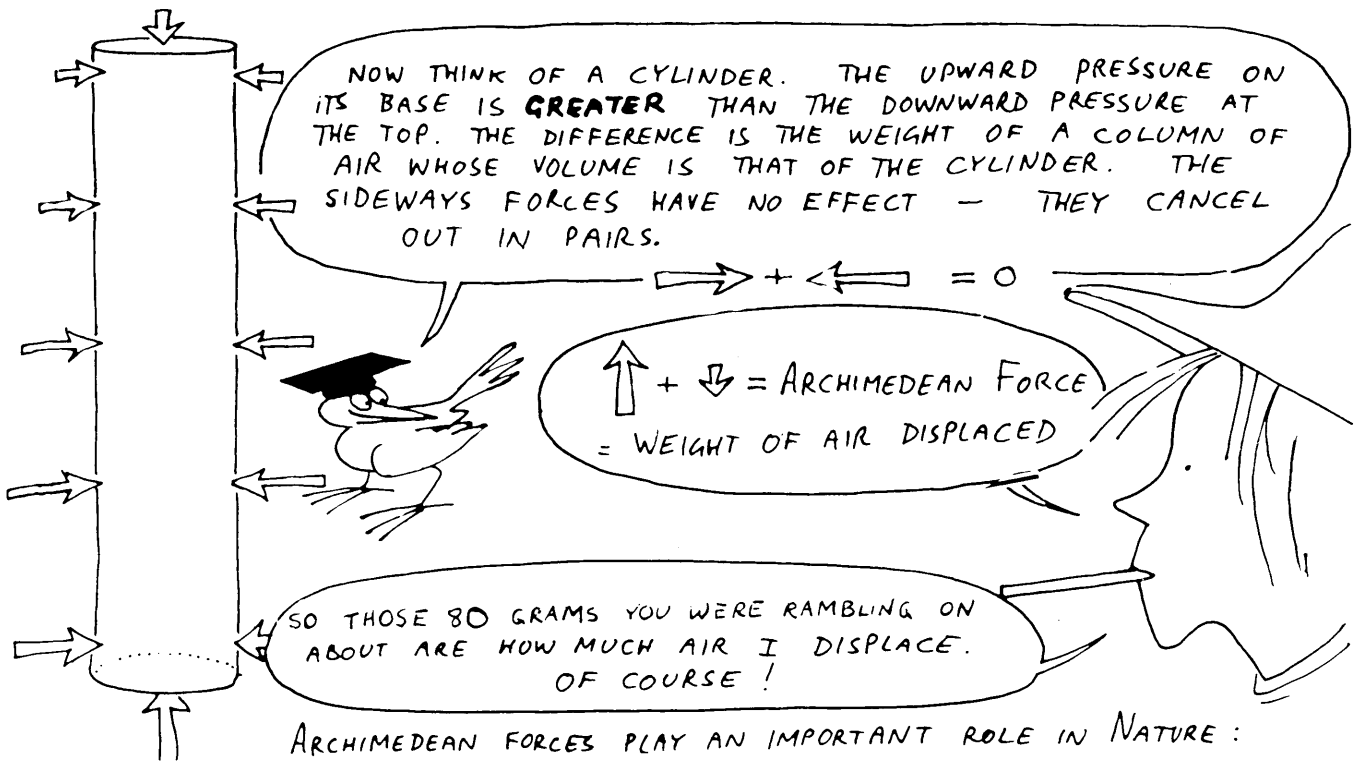


FORCES ACTING ON A DISC IMMERSED IN A FLUID:

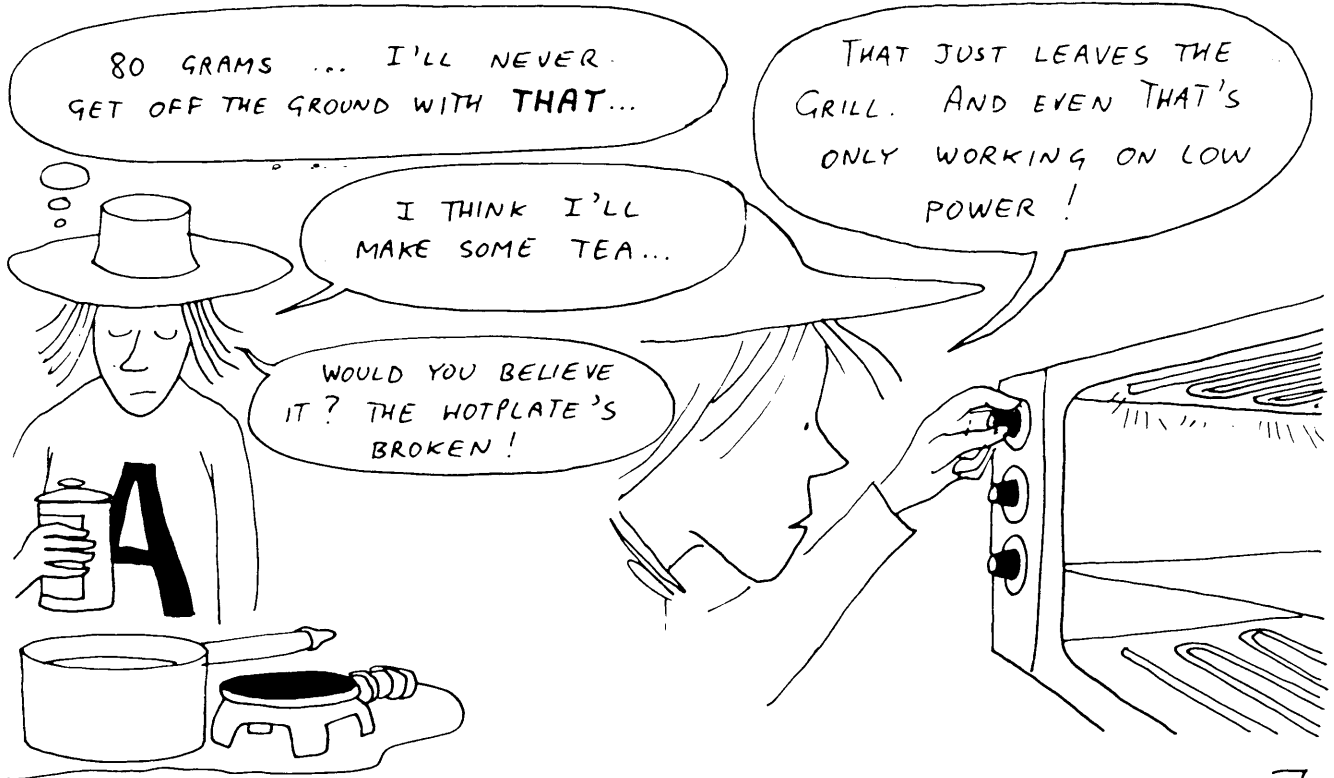


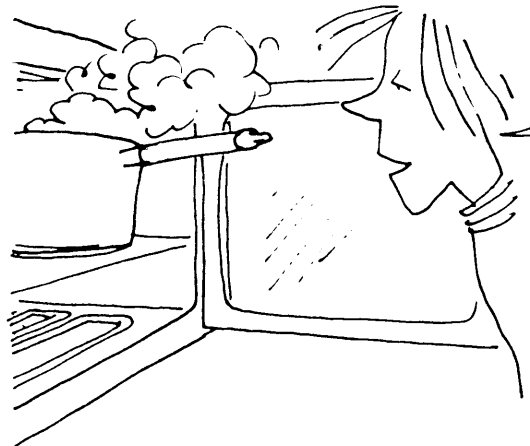
THINK OF A DISC SITTING IN THE ATMOSPHERE. THE ENTIRE COLUMN OF AIR OVER THE TOP PUSHES IT DOWNWARDS. BUT AN EQUAL AND OPPOSITE FORCE ACTS FROM UNDERNEATH — SO THE TWO PRESSURE FORCES CANCEL OUT. THE "DEEPER" THE DISC IS IN THE ATMOSPHERE, THE GREATER THESE FORCES BECOME...






CONVECTION CURRENTS







GOOD HEAVENS! IT'S
WORKING MUCH BETTER THAN I
EXPECTED! IT'S BOILING ALREADY!




HEY - THIS TEA
IS STONE COLD!



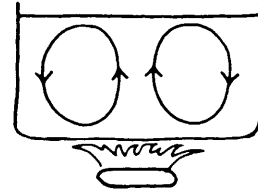
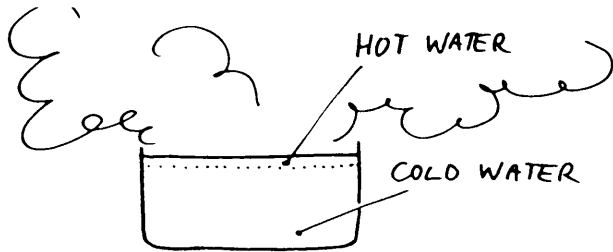
SO IS THE
WATER IN THE
SAUCEPAN!



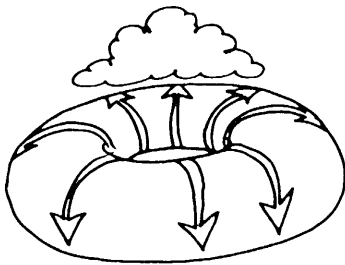
I CAN'T BELIEVE MY
EYES! THIS WATER WAS
BOILING A MINUTE
AGO!



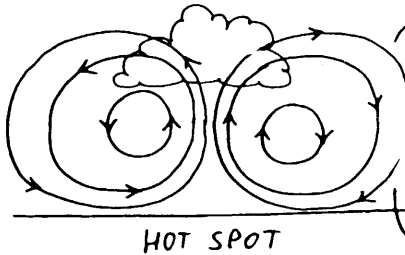
YOUR GRILL ONLY HEATS
THE TOP LAYER. AND THE FILM
OF HOT WATER IS LESS DENSE, SO
IT FLOATS. THAT'S ALL.



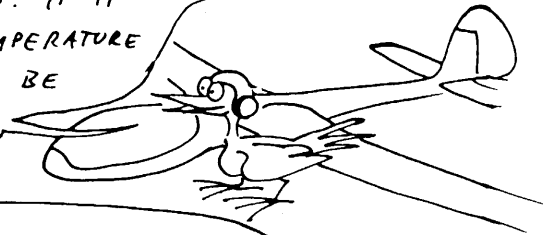
ON THE OTHER HAND, IF YOU HEAT THE WATER FROM BELOW IT GETS **LESS** DENSE, AND RISES IN A COLUMN. WHEN IT REACHES THE TOP IT COOLS, CONTRACTS, AND DESCENDS AGAIN ON THE OUTSIDE. THIS IS **NATURAL CONVECTION**.



THE SAME THING OCCURS IN THE ATMOSPHERE. WARM AIR, LADEN WITH MOISTURE, RISES FROM A HOT SPOT. WHEN IT COOLS, THE VAPOR CONDENSES, FORMING A NICE **CUMULUS CLOUD**.



THIS MIXES THE AIR AND MAKES THE TEMPERATURE MORE EVENLY DISTRIBUTED. IF IT DIDN'T HAPPEN, THE TEMPERATURE ON A SUNNY DAY WOULD BE HUNDREDS OF DEGREES.



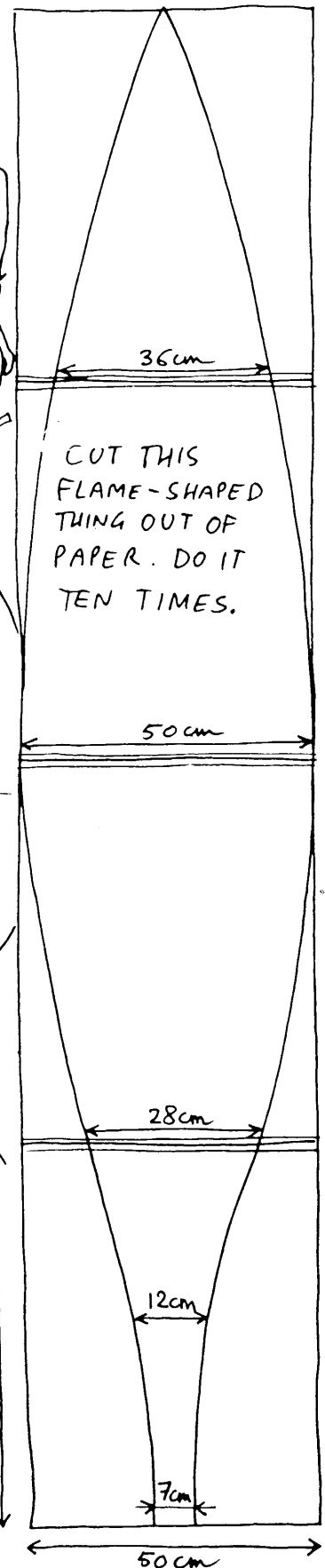
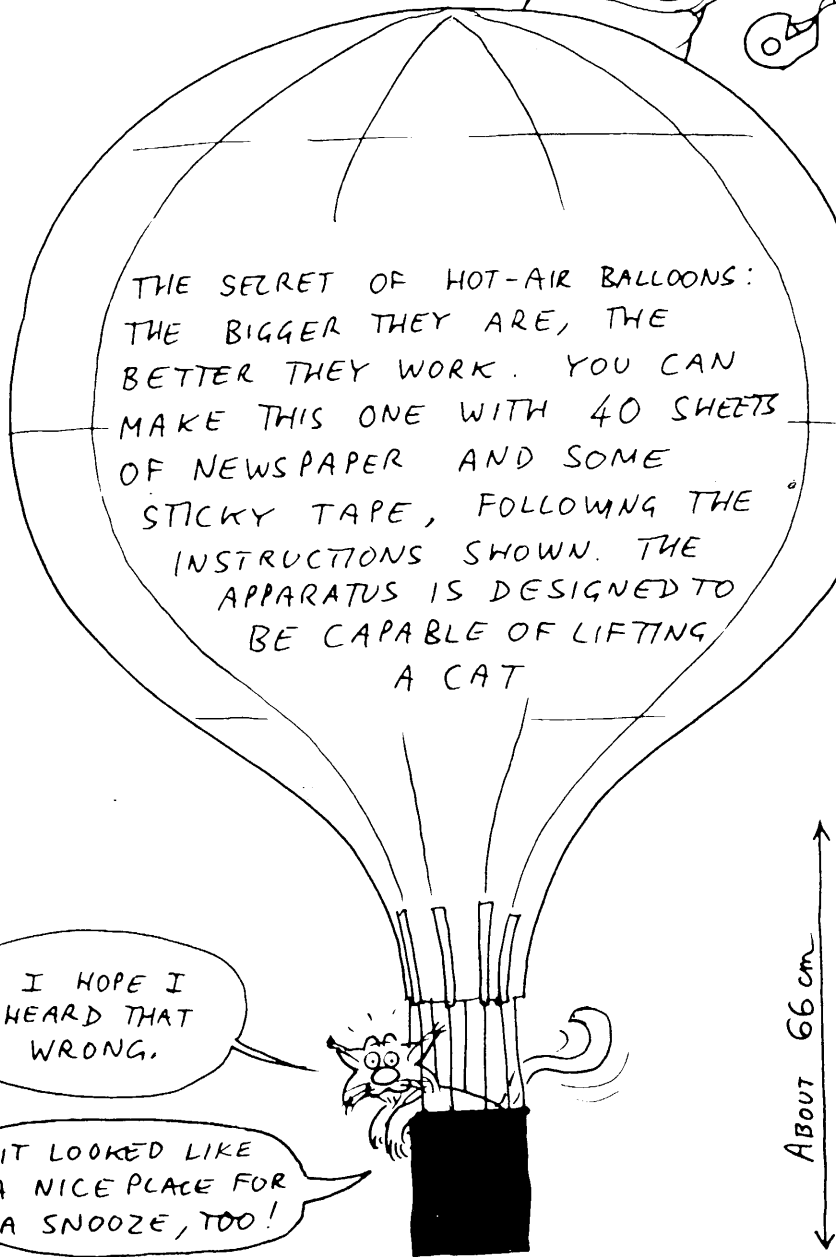
IF I HITCHED MYSELF TO ONE OF THOSE LUMPS OF WARM AIR, MAYBE I'D BE ABLE TO FLY?



WATCH WHAT YOU'RE DOING WITH THOSE HUGE FEET, YOU KLUTZ!

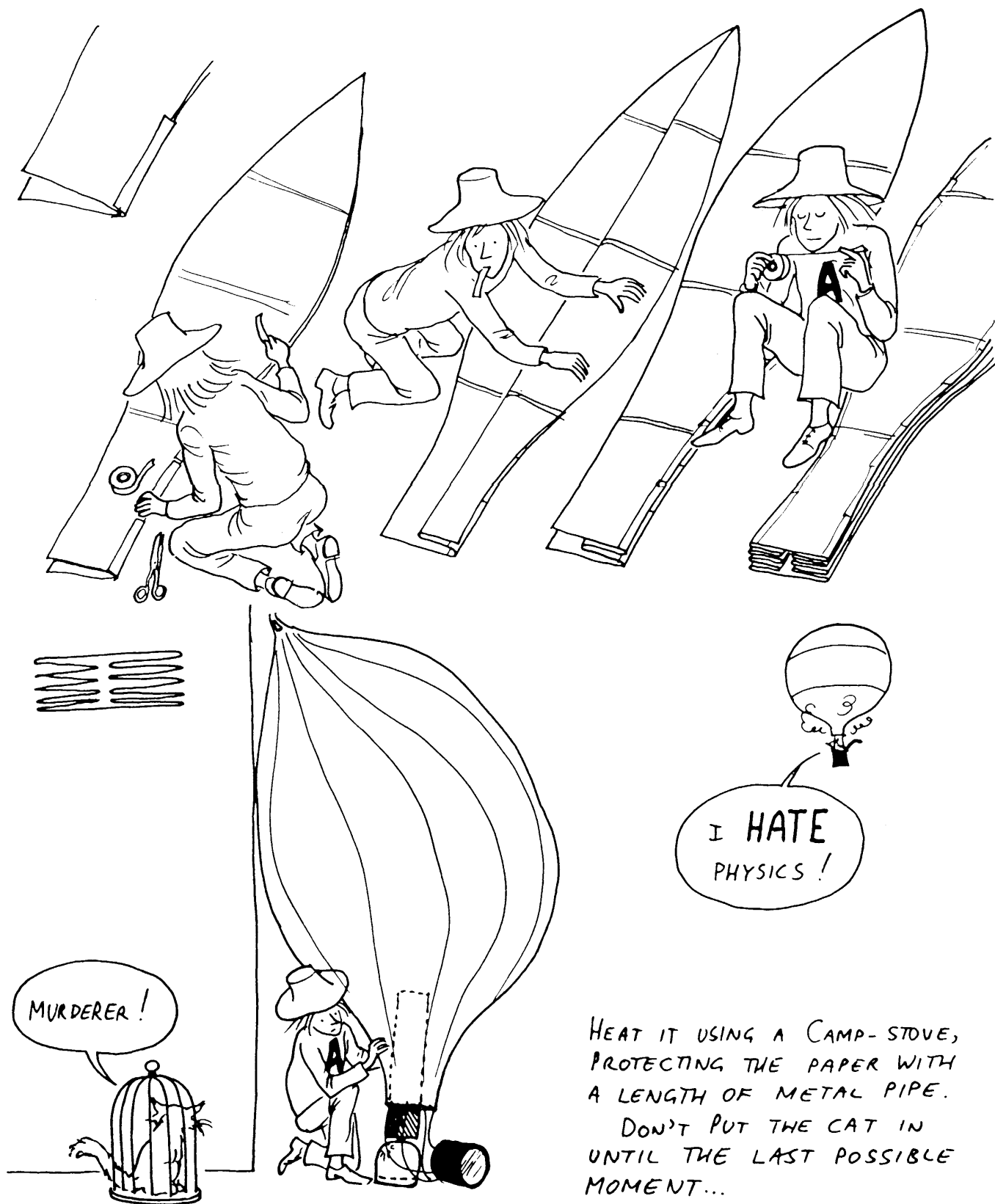


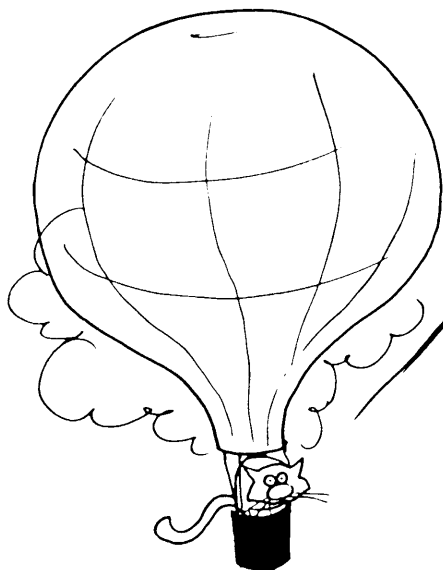
LIGHTER - THAN - AIR MACHINES



FOUR SHEETS OF NEWSPAPER, JOINED WITH STICKY TAPE

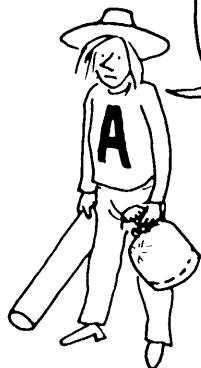
HERE'S HOW ARCHIE PUT HIS HOT-AIR BALLOON TOGETHER...





ITS FIVE-YEAR MISSION:
TO BOLDLY GO WHERE NO
CAT HAS EVER GONE BEFORE!

BEAM US
DOWN, MR.
SPOCK!




ALL RIGHT FOR PAPER TIGERS,
I SUPPOSE... BUT ALL THE HOT
AIR IN ALL THE NEWSPAPERS
OF THE WORLD WON'T GIVE **ME**
MUCH OF A LIFT...

WHAT **IS** THE SECRET
OF FLIGHT, MAX?




BUZZ OFF,
ARCHIE! I'M
WORN OUT!







NO GOOD, BLAST IT! **THIS** WON'T WORK.
I MUST HAVE MISSED SOMETHING...




OH DEAR.



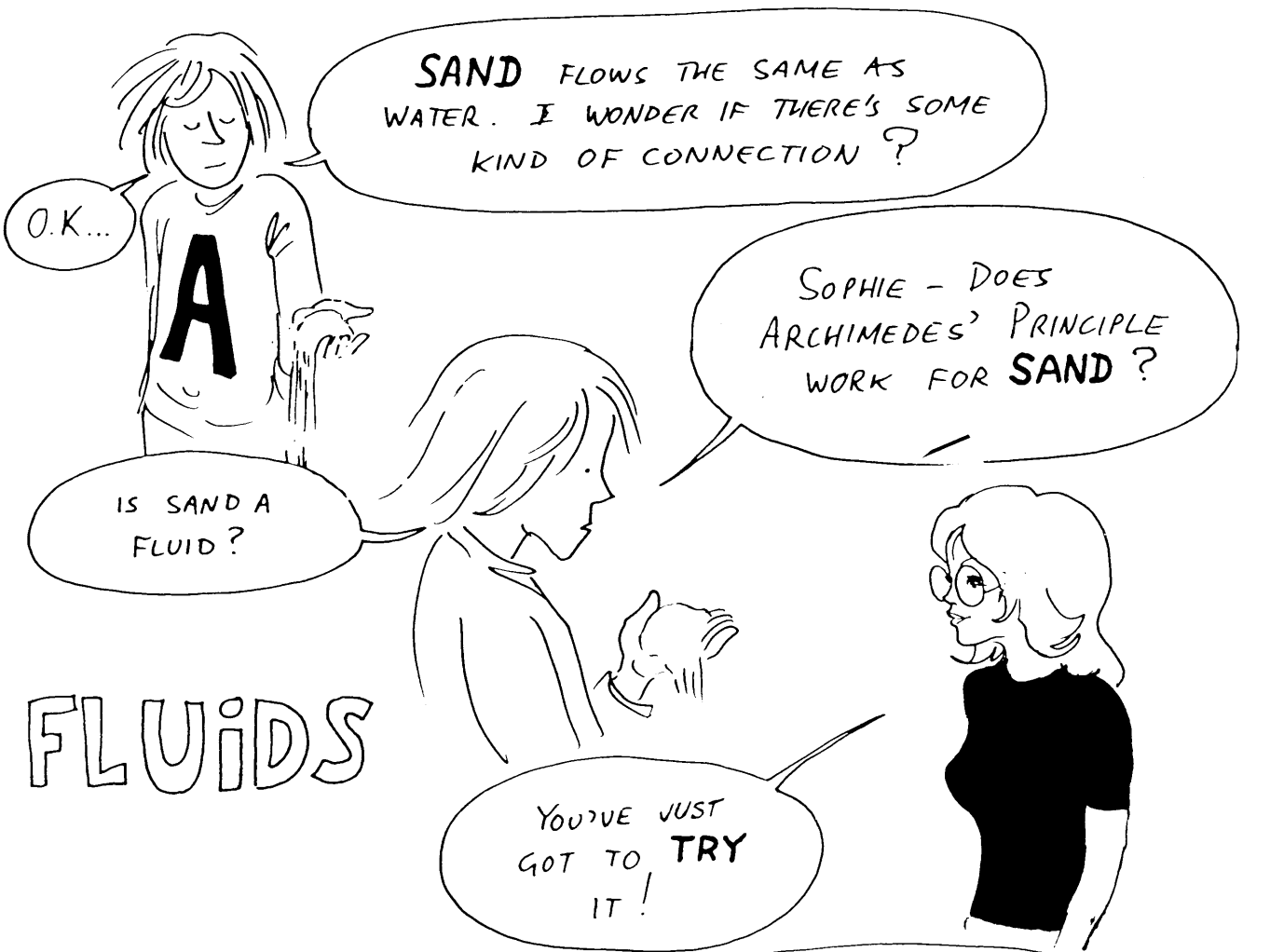
ARCHIE — TO FLY, YOU HAVE TO
KNOW SOMETHING ABOUT **FLUID
MECHANICS**. IT'S NOT AS EASY AS
YOU SEEM TO IMAGINE!



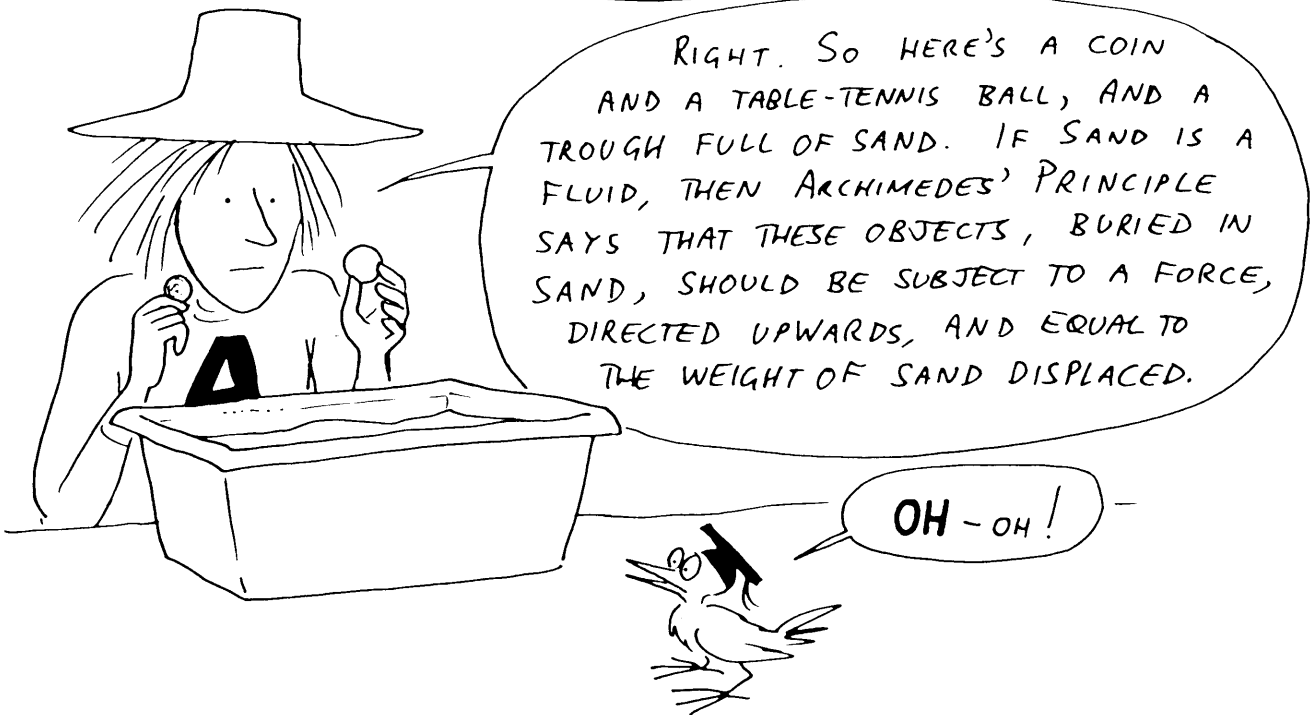
FINE — BUT WHAT
IS A FLUID? IS IT
JUST ANYTHING THAT
FLOWS?




YES, IF YOU LIKE.
BUT EVEN THAT IS
MORE COMPLICATED THAN
YOU'D THINK.




FLUIDS






I'VE BURIED THE BALL,
AND I'VE SAT THE COIN ON
TOP. LOGICALLY, THE COIN
OUGHT TO SINK, AND THE
BALL OUGHT TO RISE...

RATS !!



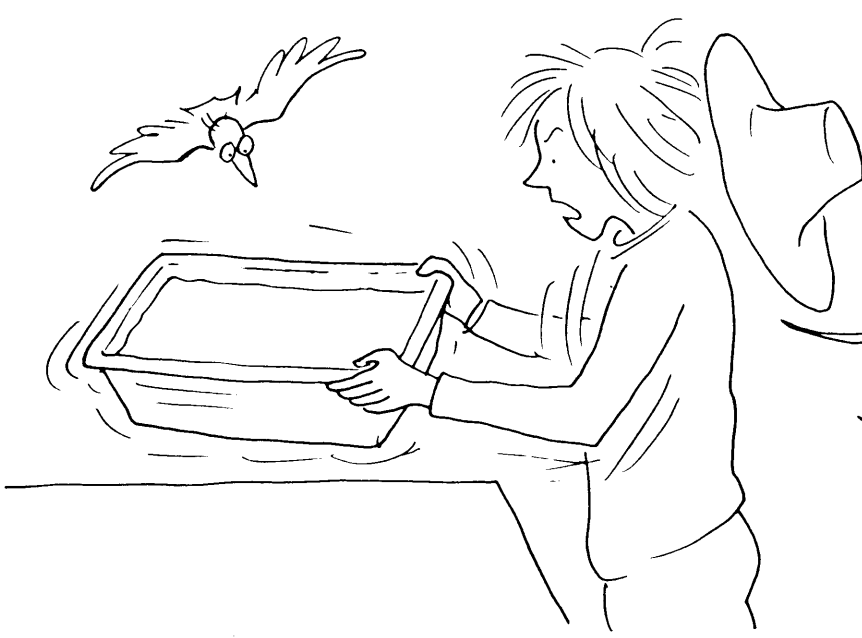
PERHAPS IT'S A
MATTER OF **TIME**...



'AS YOUR MATE
GORN **ABSOLUTELY**
BONKERS ?

YOU CAN NEVER BE TOO
CAREFUL WITH PHYSICS.

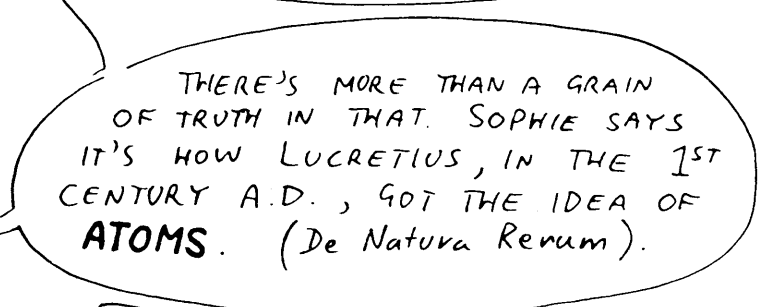
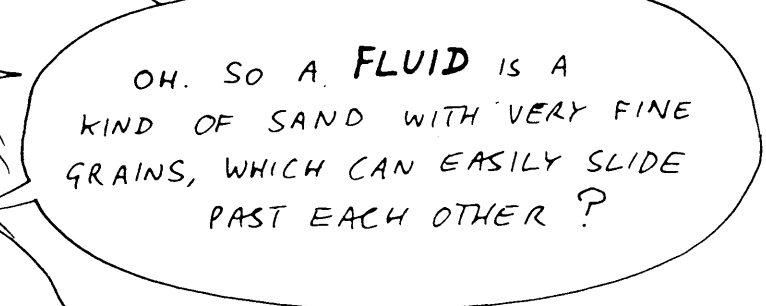
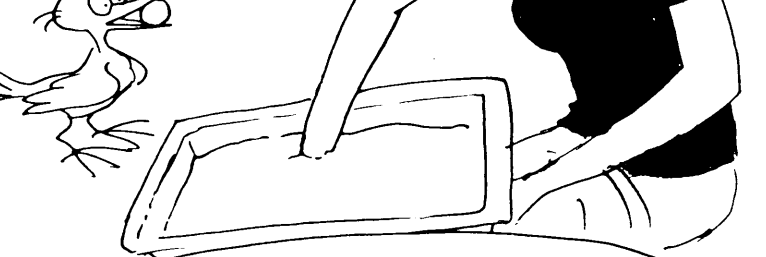
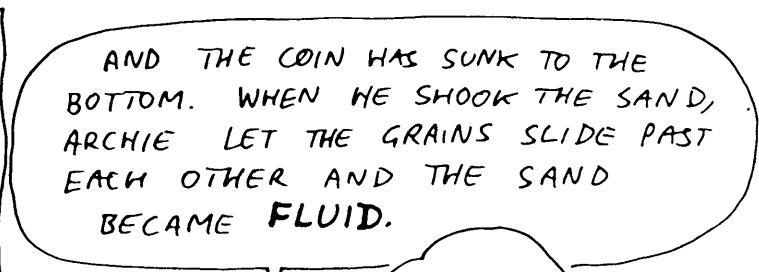
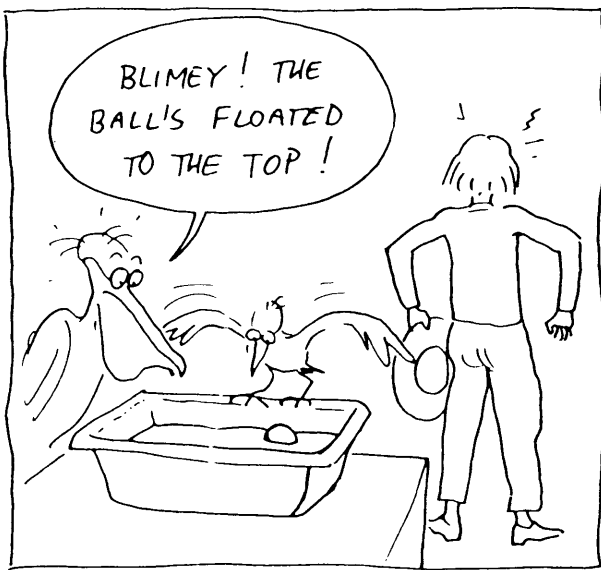
YOU CAN GET
BRAIN STRAIN.



WHAT'S UP
WITH THE SILLY
THING ?

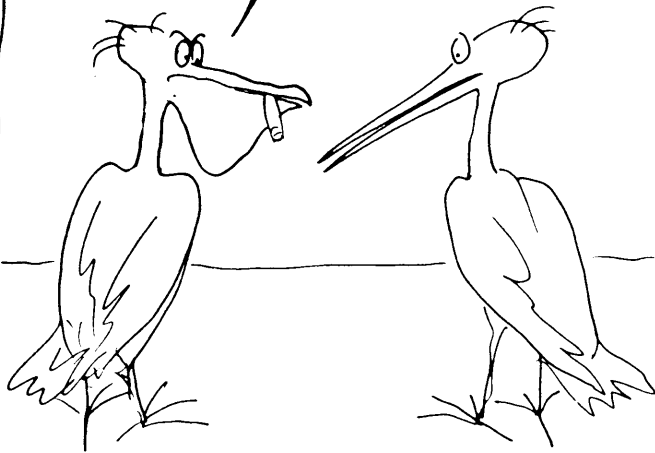
THROW PHYSIC TO
THE DOGS - I'LL
NONE OF IT !!
(*)

*SHAKESPEARE: MACBETH V iii 47

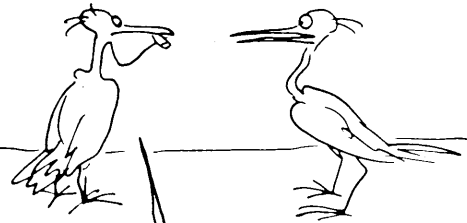


SO YER SEES, OL' DUCK -
FINGS LIKE SUET PUDDIN'S IS
JUST VERY VISCOUS FLUIDS. AN'
I RECKONS **GLASS** IS TOO...

(*)

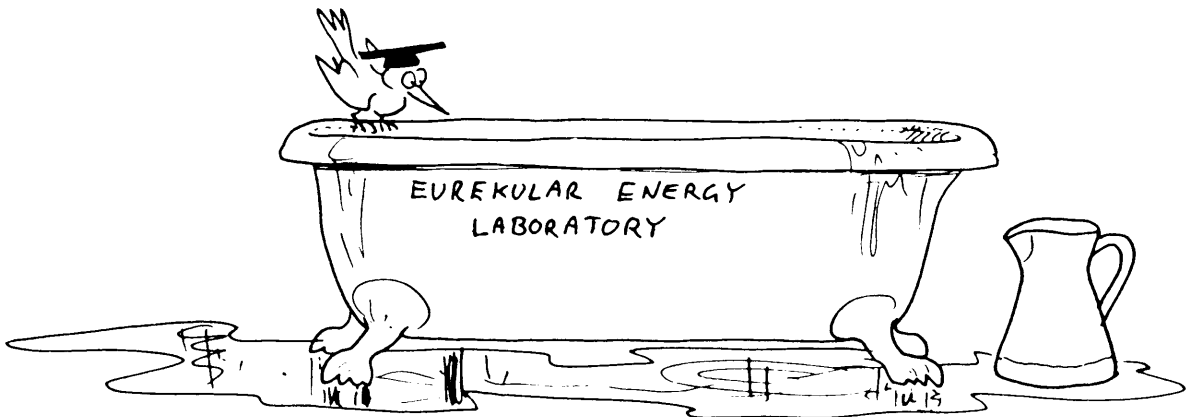


YOU MEAN TO TELL
ME THAT **ARCHIMEDES'**
PRINCIPLE —



DON'T PUT WORDS INTO MY
MOUTH, DAMN IT !!

(*) **GLASS IS EFFECTIVELY A VERY VISCOUS LIQUID.**





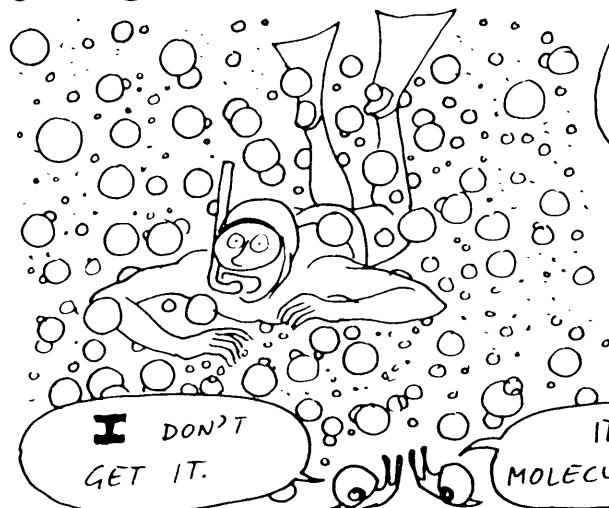
YOU SEE ARCHIE - TO UNDERSTAND A FLUID PROPERLY YOU HAVE TO REALIZE AT THE START THAT IT'S A COLLECTION OF MOLECULES, WHICH ARE LIKE TINY BALLS, BOUNCING AND SLIDING OFF AND AROUND EACH OTHER LIKE A MEGALOMANIC GAME OF BILLIARDS — **MOLECULAR CHAOS!**

O.K. LET'S HAVE SOME CHAOS!



THERE ARE TWENTY TRILLION OF THESE LITTLE BALLS IN EVERY CUBIC CENTIMETER OF THE AIR WE BREATHE. THEY'RE TOO SMALL TO SEE, EVEN WITH THE MOST POWERFUL MICROSCOPES.

DENSITY

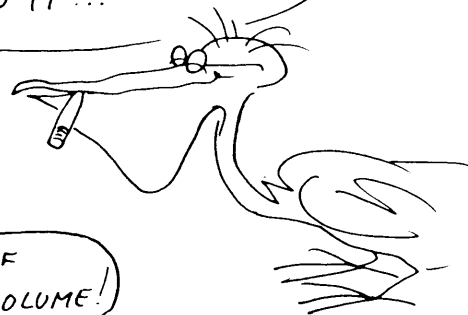


I DON'T GET IT.

THE CONCEPT OF **DENSITY** IS SO INTUITIVE THAT WE **NEARLY** DECIDED NOT TO MENTION IT...

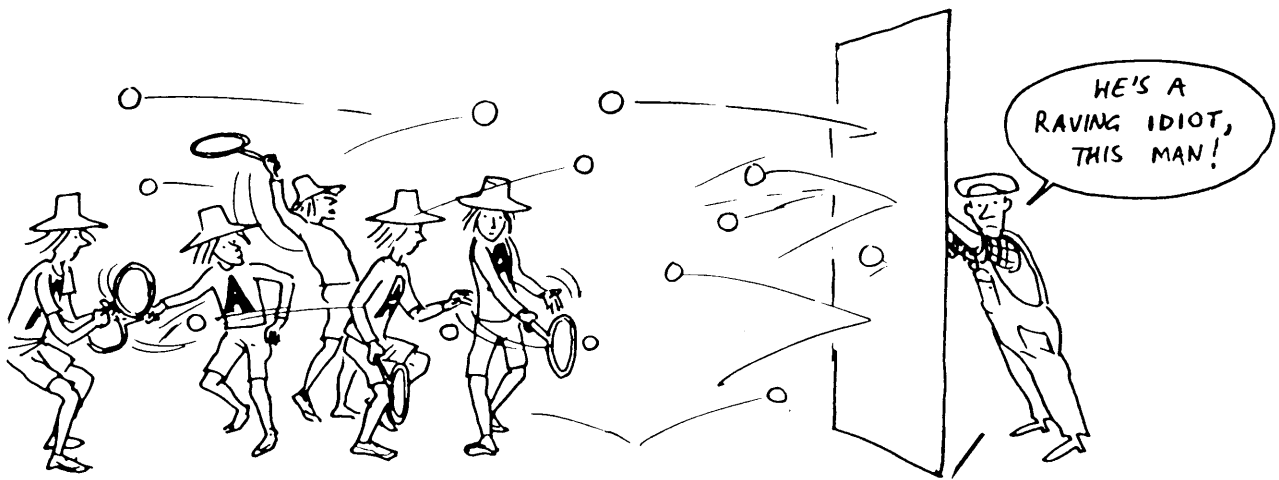


IT'S THE NUMBER OF MOLECULES PER UNIT VOLUME!

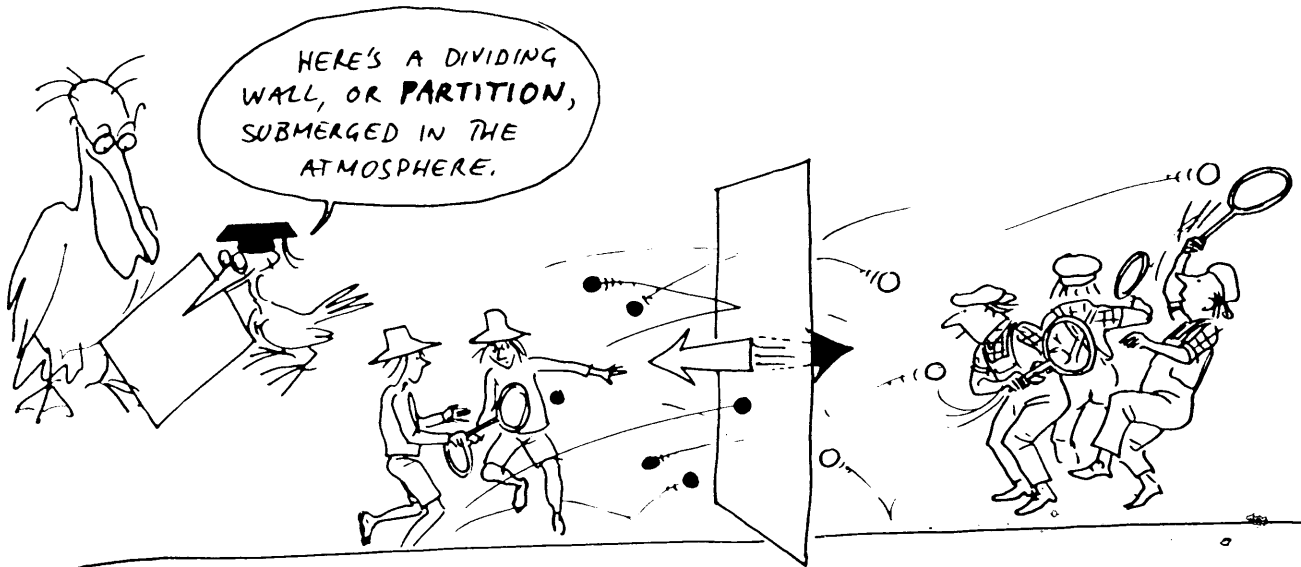


PRESSURE:

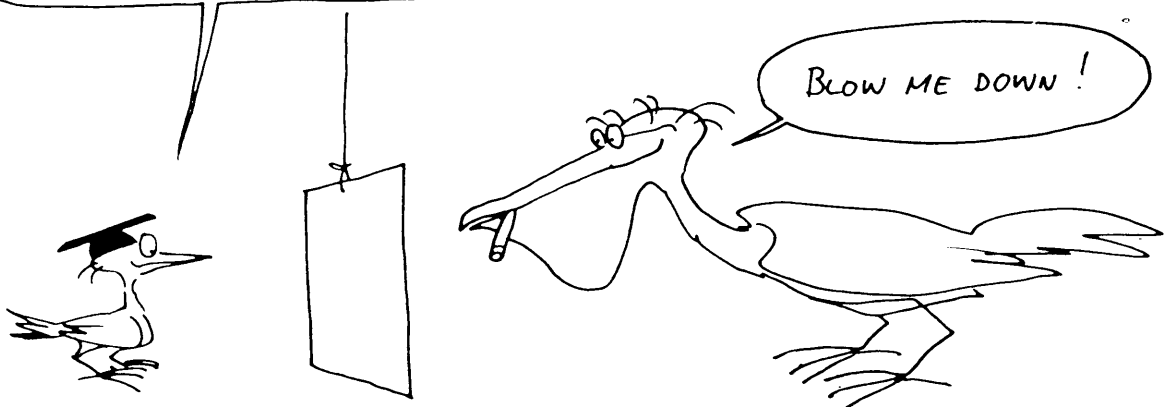




IT IS THESE INNUMERABLE MOLECULAR SHOCKS THAT HAPPEN AT A WALL, THAT PRODUCE THE EFFECT WE CALL **PRESSURE**.

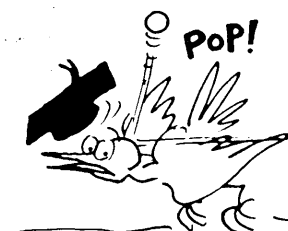


IT STAYS FIXED BECAUSE THE FORCES EXERTED ON EACH SIDE BY MOLECULAR COLLISIONS CANCEL EACH OTHER OUT.



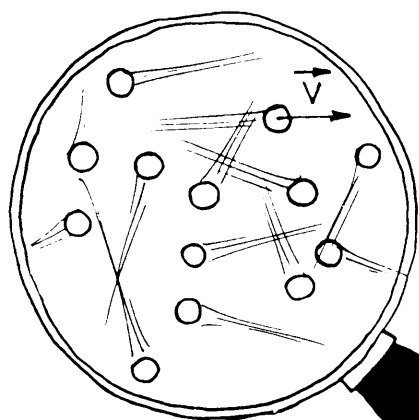
KINETIC ENERGY:

AN OBJECT OF MASS m
MOVING AT A SPEED V ...



POSSESSES, BY DEFINITION,
A **KINETIC ENERGY** EQUAL
TO $\frac{1}{2} m V^2$.

THERMAL ENERGY:

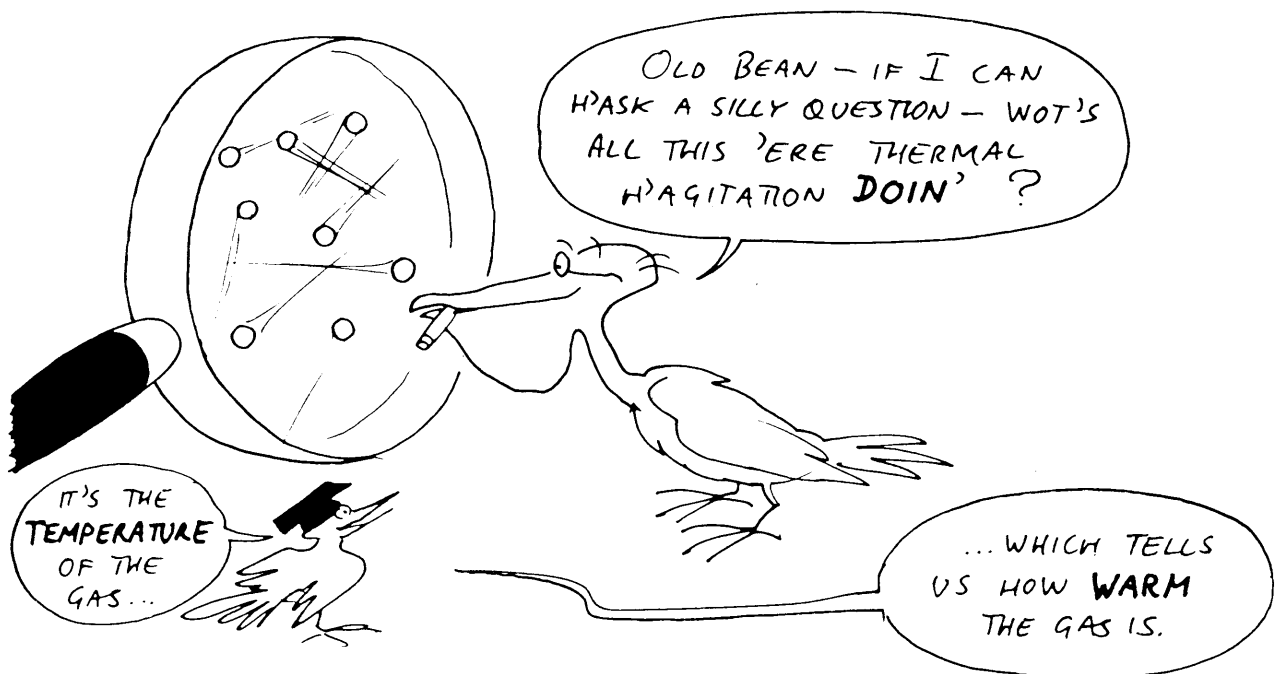


HERE'S A LUMP OF GAS. THE MOLECULES ARE
JUMPING ALL OVER THE PLACE. SUPPOSE A
MOLECULE HAS MASS m . ITS SPEED OF VIBRATION,
OR VELOCITY OF THERMAL AGITATION, IS V .

THE **THERMAL ENERGY** OF THIS LUMP,
(OR **SYSTEM**) IS JUST THE SUM OF THE
CONTRIBUTIONS $\frac{1}{2} m V^2$ OF THE KINETIC
ENERGIES OF THE INDIVIDUAL MOLECULES
CONTAINED IN IT.

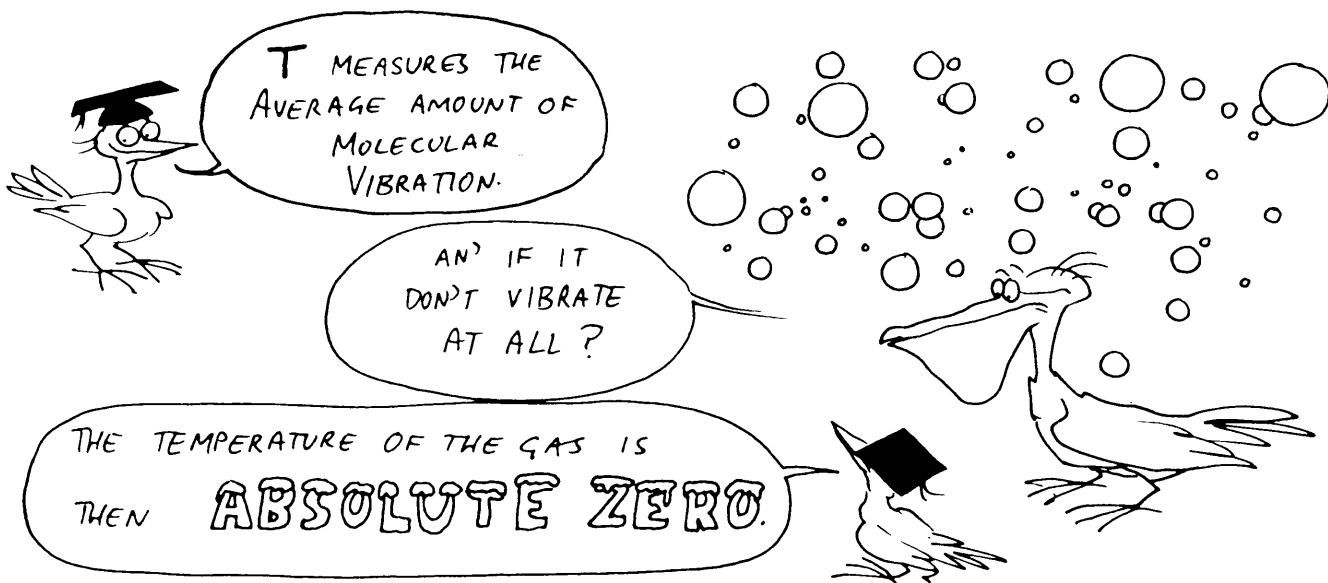


TEMPERATURE:



THE **ABSOLUTE TEMPERATURE** OF A GAS IS THE SIZE $T = \frac{1}{2} m v^2$ OF THE KINETIC ENERGY OF AGITATION OF A MOLECULE OF THE GAS.

The Boss



YER CAN'T GET NO LOWER
ON THAT, CAN YER? YER
CAN'T MOVE ANY LESS THAN
NOT MOVIN' AT ALL, EH?

NO MOLECULAR VIBRATION —
NO COLLISIONS ON WALLS — SO
NO PRESSURE !

CRUIKEY —
I'VE UNDERSTOOD
IT !



TO RECAP : THE MORE MOLECULES,
THE MORE THEY HOP AROUND — WARM
UP — AND THE HIGHER THE PRESSURE
GETS

HEAT



WHEN AN OBJECT IS PLACED IN A FLUID, IT
UNDERGOES AN ENORMOUS NUMBER OF
MOLECULAR MICROSHOCKS . IN THIS WAY, THE
MOLECULES CAN TRANSMIT OR EXCHANGE
ENERGY, OR **HEAT**. THE POWER TO TRANSMIT
HEAT INCREASES WITH THE DENSITY OF THE
FLUID.

FOR THIS REASON, WATER IS A BETTER
CONDUCTOR OF HEAT THAN AIR IS.



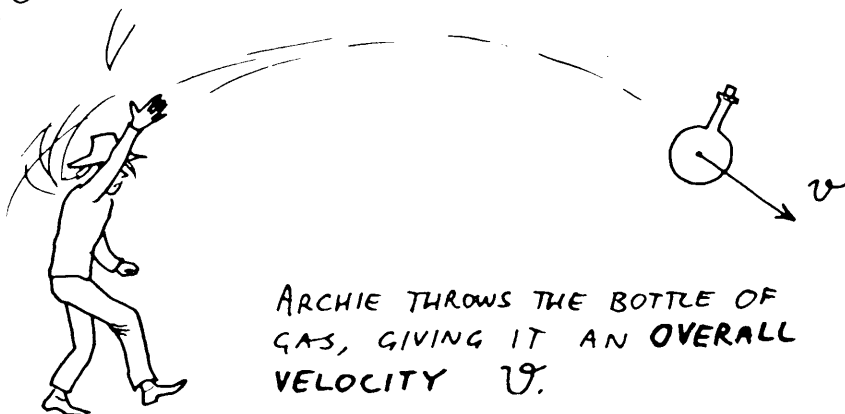
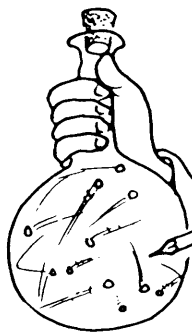
WHEN AN ASTRONAUT "WALKS" IN SPACE, HE MOVES IN A HIGHLY RAREFIED ATMOSPHERE (10 MOLECULES PER CUBIC CENTIMETER). THE DEGREE OF VIBRATION OF THE MOLECULES CORRESPONDS TO A TEMPERATURE OF 2500°C — BUT THIS DOESN'T ROAST THE ASTRONAUT, BECAUSE THE AIR IS SO THIN THAT THE TOTAL HEAT TRANSMITTED IS SMALL

BRRR! 2500°C AND I'M FREEZING!

THE TEMPERATURE IS HIGH BUT THE HEAT FLUX IS FEEBLE.

OVERALL ENERGY

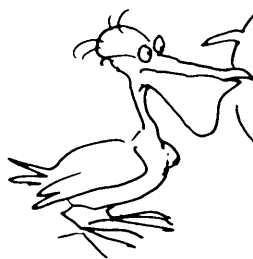
HERE IS A COLLECTION, A SYSTEM OF N MOLECULES, AT AN ABSOLUTE TEMPERATURE T .



ARCHIE THROWS THE BOTTLE OF GAS, GIVING IT AN OVERALL VELOCITY v .

TO THIS OVERALL VELOCITY v CORRESPONDS AN OVERALL KINETIC ENERGY $\frac{1}{2} M v^2$, M BEING THE MASS

OF GAS CONTAINED IN THE BOTTLE.



YER TELLIN' ME THERE'S TWO SORTS OF KINETIC ENERGY, AIN'T YER ?



YES AND NO, OLD PAL — THE SYSTEM OF MOLECULES IN THE FLASK HAS A **TOTAL** ENERGY, WHICH IS THE SUM OF THE OVERALL ENERGY AND THE ENERGY OF THERMAL AGITATION.



YOU'RE RIGHT — IT'S CONFOUNDEDLY COMPLICATED, FLUID MECHANICS !

YOU WANT TO FLY ? THEN SPREAD YOUR WINGS A LITTLE !



O.K. THE BOOK SAYS THAT, IN A SYSTEM OF MOLECULES, YOU CAN TURN THERMAL ENERGY INTO OVERALL ENERGY.

IN UUVVER WORDS — 'EAT INTO MOTION !!

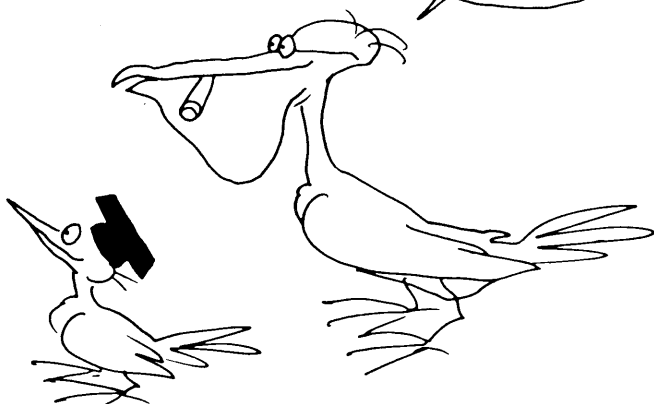




ALL YOU HAVE TO DO IS
TAKE THE CORK OUT.

SYSTEM OF MOLECULES:
THERMAL ENERGY
 $N \times \frac{1}{2} m V^2$

GO ON
THEN !



CONSERVATION OF ENERGY



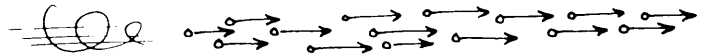
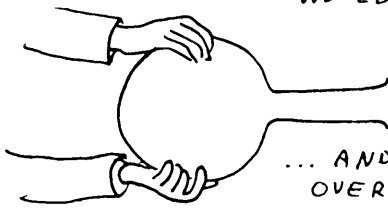
WHAT
THE -

FOR SIMPLICITY, WE
ASSUME THIS ESCAPE OF
THE GAS TAKES PLACE
WITH NO OUTSIDE OBSTACLE,
IN A VACUUM.

The Boss

$V =$
SPEED OF
AGITATION
OF THE N
MOLECULES

IF ALL THE HEAT WERE CHANGED INTO MOTION, THE MOLECULES WOULD ALL HAVE THE SAME (OVERALL) VELOCITY v ...



... AND THE ENERGY OF THE SYSTEM WOULD BE THE OVERALL ENERGY $N \times \frac{1}{2} m v^2$.

BY THE PRINCIPLE OF CONSERVATION OF ENERGY, THE TOTAL ENERGY OF THE SYSTEM - THAT IS, THE SUM OF THE OVERALL ENERGY AND THE THERMAL ENERGY OF AGITATION - IS CONSTANT IN THIS PROCESS.

The Boss



TELL ME IF I GOT IT RIGHT, OLD FRUIT.
H¹IN THE PARTICKLER CASE OF TOTAL RELEASE,
CONSTIPATION OF H¹ENERGY GIVES $N \times \frac{1}{2} m v^2$
 $= N \times \frac{1}{2} m v^2$, SO $V = v$?



WELL,
NEAR
ENOUGH

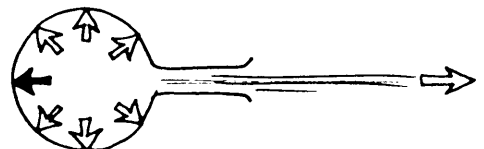
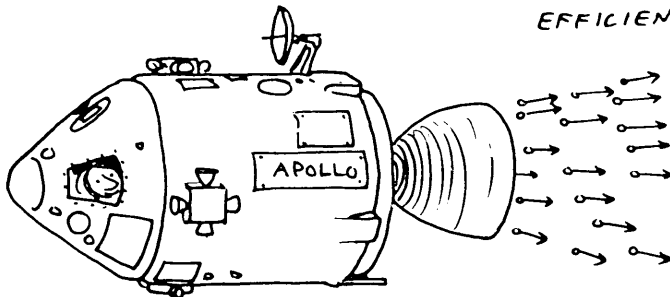
ONE APPLICATION OF THIS TRANSFORMATION OF HEAT INTO MOTION IS:

REACTION ~ PROPULSION

THE NOZZLE OF A ROCKET MOTOR, OR "EGGCUP," HAS A GEOMETRY WHICH REALIZES THE TRANSFORMATION HEAT \rightsquigarrow MOTION AS

EFFICIENTLY AS POSSIBLE. THE PROPULSIVE

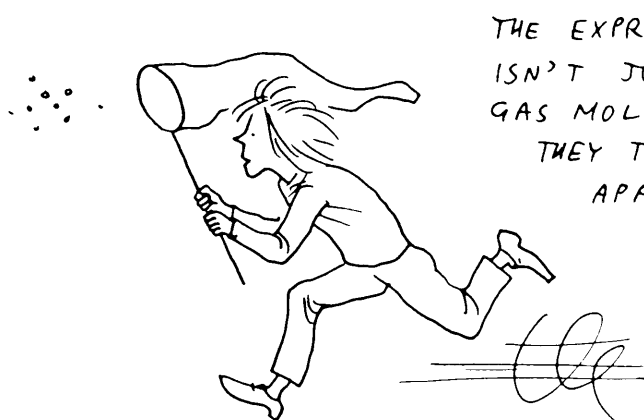
FORCE ARISES BECAUSE, AS THE GAS ESCAPES, THE PRESSURE



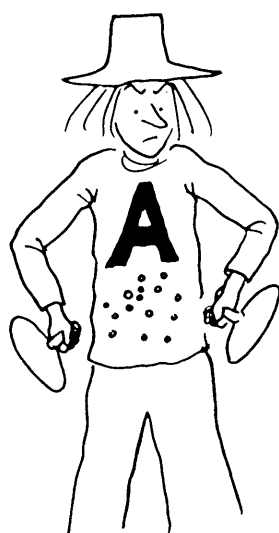
ON THE CONTAINER IS NO LONGER ZERO.



INCOMPRESSIBLE FLOW



THE EXPRESSION "FREE AS THE AIR"
ISN'T JUST A HOLLOW PHRASE...
GAS MOLECULES HATE CROWDS.
THEY TRY TO STAY AS FAR
APART AS POSSIBLE.



I'LL NEVER MAKE
THE AIR DENSER
THIS WAY !

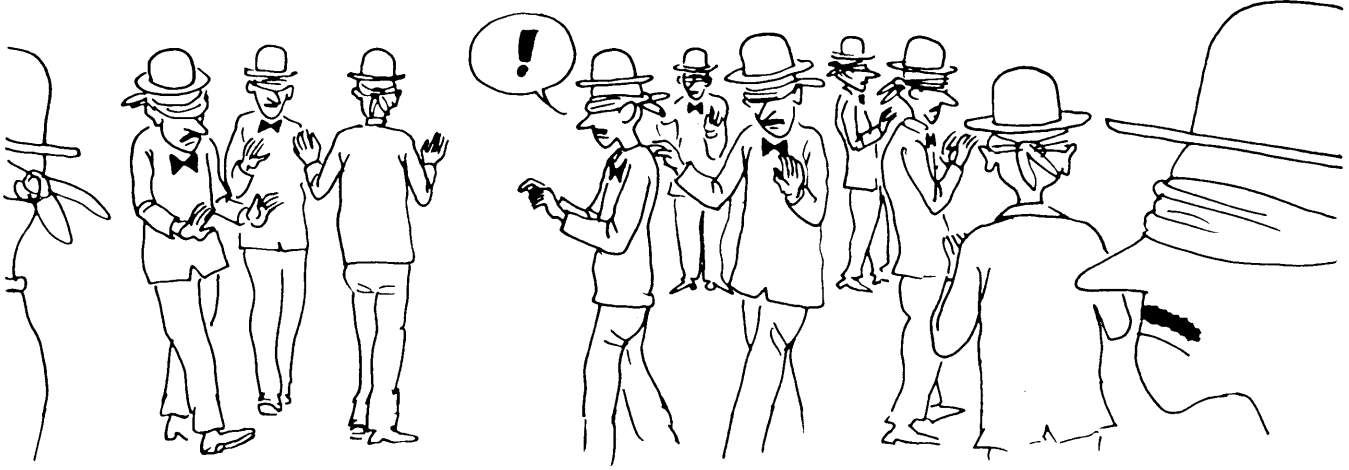
YAH, MISSED !
YOU'RE TOO SLOW !
I SAW YOU COMING !

WHY DO THE MOLECULES GET OUT OF THE WAY AS SOON AS
THE PADDLES COME TOGETHER ?



THEY GET
SCARED ?

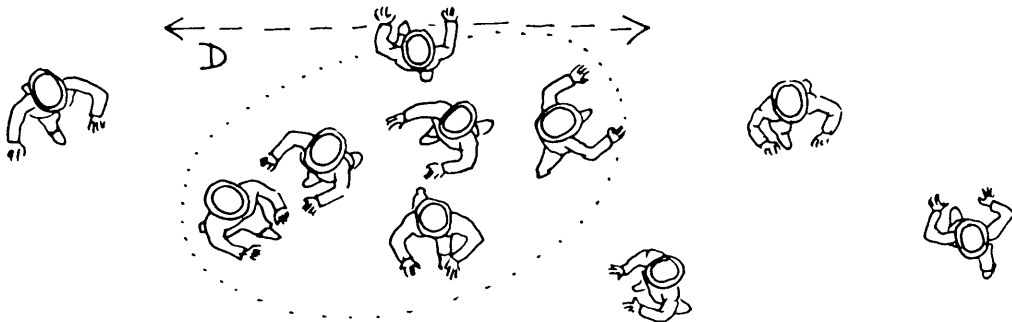
TO SEE WHAT THE MOLECULES ARE DOING, IMAGINE A PLACE WHERE EVERYBODY WANDERS AROUND WITH BLINDFOLDS ON. THE PEOPLE WILL PLAY THE ROLE OF MOLECULES — AND THE SPEED THEY MOVE AT, HAPHAZARDLY (MORE HAZARD THAN HAP!) IS THE ANALOG OF THE THERMAL AGITATION V .



THEY GO NOWHERE IN PARTICULAR. EVERY t SECONDS, ON AVERAGE, AFTER TRAVELLING A DISTANCE L , THEY COLLIDE. WE CALL L THE MEAN FREE PATH AND t THE MEAN FREE TRAVEL TIME.

IN THE ATMOSPHERE, V — THE SPEED OF THERMAL AGITATION — IS ABOUT 340 m /second. THE MEAN FREE PATH OF A MOLECULE IS CLOSE TO A HUNDRED THOUSANDTH OF A CENTIMETER, SO THE TIME ELAPSING BETWEEN TWO COLLISIONS OF A MOLECULE WITH ITS NEIGHBORS IS ONLY ONE TEN THOUSAND MILLIONTH OF A SECOND.

THERE IS NOTHING TO MAKE THESE BLINDFOLDED PEOPLE COLLECT TOGETHER. ON THE CONTRARY — THEIR RANDOM MOVEMENTS TEND TO DISPERSE ANY GROUP OF DIAMETER D IN A TIME D/V .



ESSENTIALLY THIS IS THE TIME ONE PERSON TAKES TO MOVE DISTANCE D — THEREBY LEAVING THE GROUP.



THESE PEOPLE - WHO WE ASSUME ARE ALSO STRUCK SPEECHLESS - CAN ONLY "SEE" AS FAR AS THEIR ARMS CAN REACH. IF SOMETHING MOVES INTO THE CROWD AT A SPEED U LOWER THAN THEIR SPEED OF MOVEMENT V , THEN THE PEOPLE CAN TELL EACH OTHER ABOUT IT, STEP BY STEP, BY BUMPING INTO EACH OTHER. SO THEY CAN GET OUT OF THE WAY BEFORE THE OBJECT HITS THEM.

THIS INFORMATION MOVES AT THE SAME SPEED THEY DO - THAT IS, THE VELOCITY OF AGITATION V .

SOUND

IS THE PROPAGATION, AT CONSTANT DENSITY, OF A PRESSURE - IMPULSE. IT'S A SORT OF WAVE OF JOSTLING, AND IT MOVES WITH A SPEED EQUAL TO V .

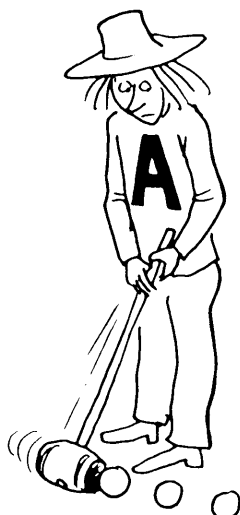


IT'S IMPORTANT TO REALIZE THAT SOUND IS A PROPAGATION OF IMPULSES, AND NOT A PROPAGATION OF MATTER.

SOUND IS A PRESSURE WAVE.

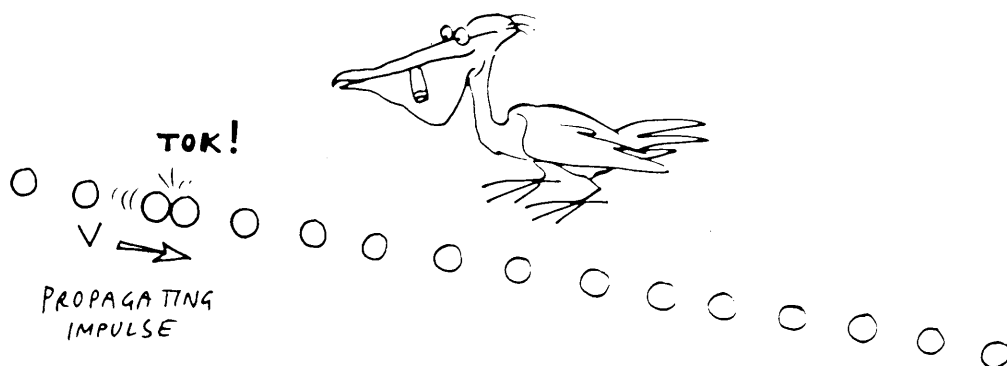


THE MOLECULES FLED FROM ARCHIE'S PADDLES AT THE SPEED OF SOUND. THEY COULD DO THIS EASILY WHILE MAINTAINING CONSTANT DENSITY, BECAUSE THE BATS WERE MOVING MUCH MORE SLOWLY THAN SOUND.

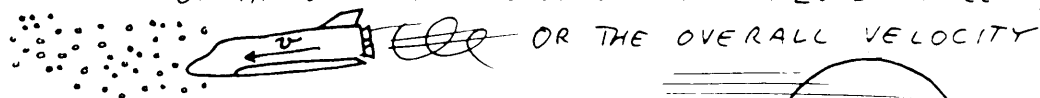


ARCHIE LINES UP SOME CROQUET BALLS. HE GIVES AN IMPULSE TO THE FIRST ONE, WHICH TRANSMITS IT TO THE SECOND, AND THIRD... AND SO ON.

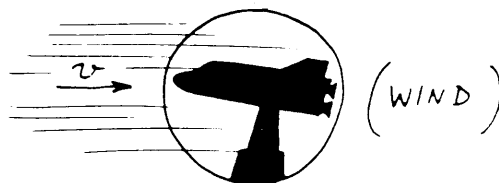
THIS IS A ONE-DIMENSIONAL IMAGE OF THE PROPAGATION OF SOUND.



THE NOTION OF SPEED IS **RELATIVE**. So v CAN EQUALLY WELL BE THE SPEED OF AN OBJECT ENCOUNTERING A FLUID AT REST,



OF GAS IMPINGING ON A **FIXED** OBJECT.



THE RATIO $M = \frac{v}{V}$ WILL BE CALLED, BY DEFINITION, THE **MACH NUMBER**. V IS THE **SPEED OF SOUND**.

IF $v < V$, THAT IS, IF $M < 1$, THE FLUID IS SAID TO BE IN THE **SUBSONIC REGIME**. THE FLOW TAKES PLACE AT CONSTANT DENSITY, AND IS SAID TO BE **INCOMPRESSIBLE**.

The Boss

BERNOULLI'S LAW

IT'S A BIT
SMELLY IN HERE!
PHEW!

IT SMELLS OF MOLES —
WHAT ELSE DO YOU EXPECT?

LET ME SEE, LET ME SEE...
DANIEL BERNOULLI, SWISS
PHYSICIST, 1700-1782 ...

?

THAT'S IT. IT
OUGHT TO WORK.

WHAT'S HE PLAYING
AT UP THERE?

THERE, THAT'S IT.

THAT'S
WHAT?

MY AUTOMATIC
VENTILATION SYSTEM.

THE WIND'S BLOWING. GREAT!
YOU CAN **FEEL** THE SUCTION.

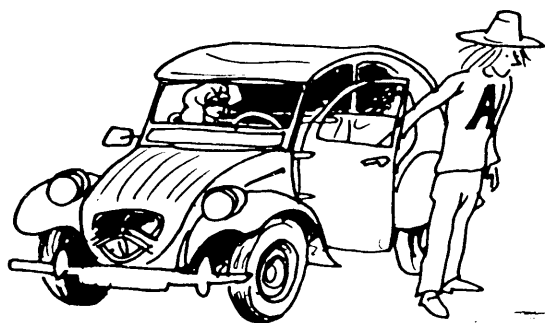
?!?

YES, BUT **WHY** DOES
THE AIR GET SUCKED OUT
OF THE BURROW?

THE MOUND GETS
IN THE WAY OF THE AIR.
TO GET PAST IT, THE
AIR HAS TO **SPEED**
UP.

SPEED UP?
WHY?





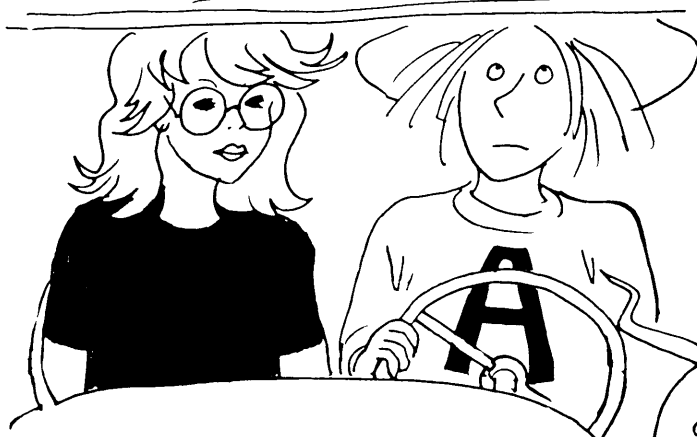
HOW HAVE YOU MANAGED
TO BECOME SO KNOWLEDGEABLE?

OH, I'VE
BURROWED INTO A
LOT OF THINGS!

IT'S FUNNY — WHEN WE STOP THE ROOF IS ALL SLACK
AND HANGS DOWN INSIDE; BUT NOW THAT WE'RE MOVING IT'S
SWOLLEN OUTWARDS!



AND YET
THE AIR IS
PUSHING AGAINST
IT.



IT'S JUST LIKE THE
MOLEHILL. YOU KNOW, THIS
CAR LOOKS QUITE LIKE
ONE, DOESN'T IT?

OH — SO THE AIR HAS TO
ACCELERATE TO GET PAST THE
CAR AT CONSTANT DENSITY.
THEN THE TEMPERATURE DROPS,
THE PRESSURE DOES TOO — AND
THE ROOF SWELLS. I
SEE NOW.

THE SAME EFFECT MAKES THE PERFUME
COME OUT OF MY **SPRAY**.

... AND IT SUCKS SMOKE UP
CHIMNEYS - WITH HELP FROM THE
WIND.

I NEVER
KNEW CHIMBLEYS
SPOKE BEFORE!

NUTS. I'D
ALWAYS FOUGHT THAT
THE AIR GOT **TRAPPED**
IN THIS BLOOMIN'
FUNNEL!

HERE IS AN ANNOUNCEMENT:

BERNCULLI'S LAW:

PRESSURE AND SPEED
VARY INVERSELY

The Boss

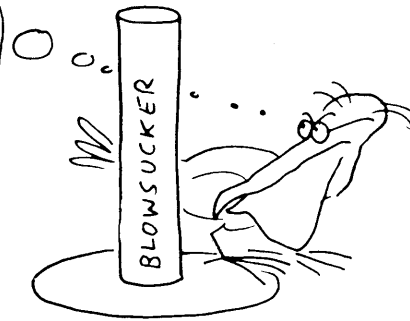
IT'S TRUE - FLUID MECHANICS REALLY DOES DEFY
INTUITION AND COMMON SENSE.

EXAMPLE OF A

PARADOX

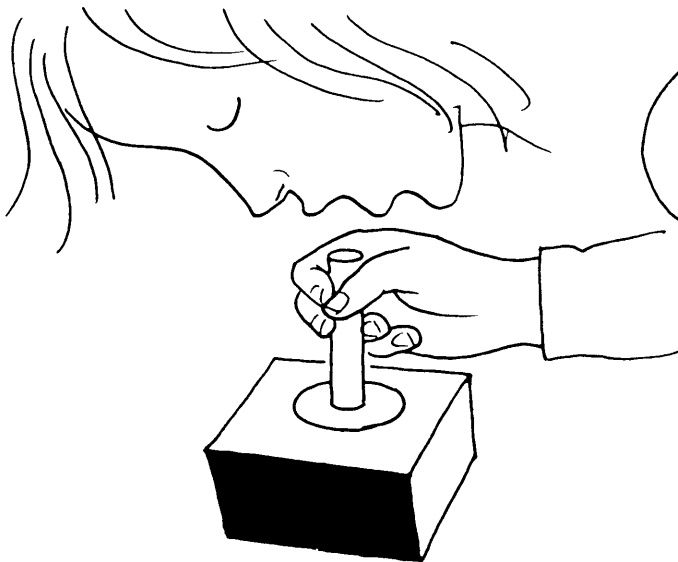
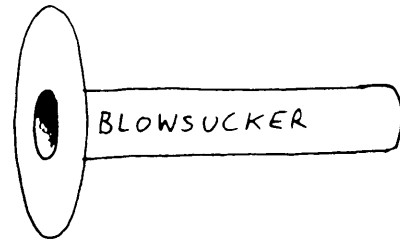
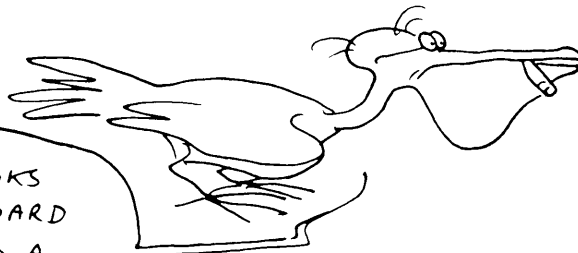
RELATED TO BERNOULLI'S LAW...

IT SURE
AIN'T H'INTUITIVE,
AN' THAT'S A
FACT! Now—



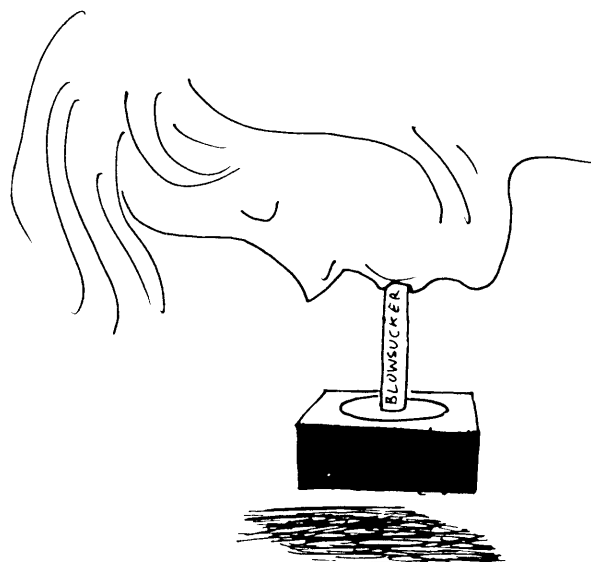
'ERE, WOT'S THIS
'ERE THERE THEN?
ANUVVER ONE OF
THEIR BLEEDIN'
TOYS?

IT JUS' LOOKS
LIKE A CARDBOARD
CHOOB STUCK TO A
DISC...

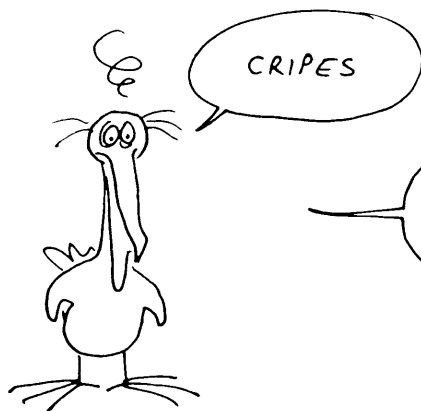
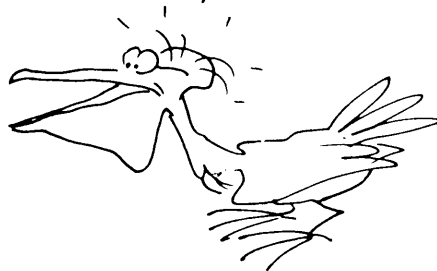


NOW WHY'S 'E
STICKIN' THE CHOOB
ON TO THAT BOX OF
MATCHES?



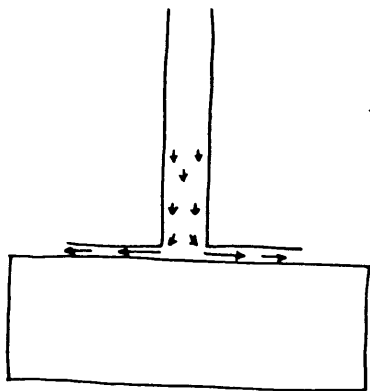


WOTTHE'ECK ?
'E - 'E'S **BLOWIN'**
AN' IT'S **LIFTIN'** THE
BOX !!

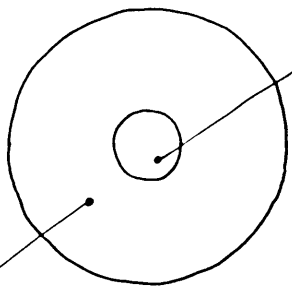


'OW CAN YER **SUCK**
BY **BLOWIN'** ?

AT THE JUNCTION OF THE CYLINDER AND THE
DISC, THE WIDTH FOR THE GAS TO PASS THROUGH
DROPS SUDDENLY, AND THE AIR SPEEDS UP
VIOLENTLY. THE PRESSURE DROPS BELOW
THAT OF THE ATMOSPHERE.



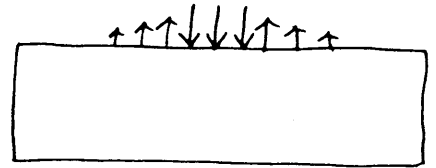
... THE OUTSIDE PART IS
AT A **LOWER** PRESSURE
THAN THE ATMOSPHERE.



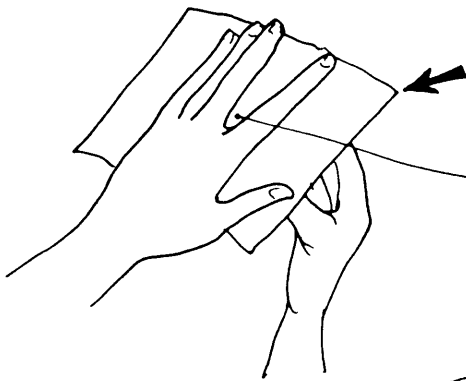
THE PART OF THE BOX
OPPOSITE THE HOLE IN
THE TUBE IS AT A
HIGHER PRESSURE THAN
ITS SURROUNDINGS...



IT TURNS OUT THAT THE RESULT
OF ALL THAT IS **SUCTION**...



YOU CAN PRODUCE A SIMILAR EFFECT
USING ONLY A SHEET OF PAPER.

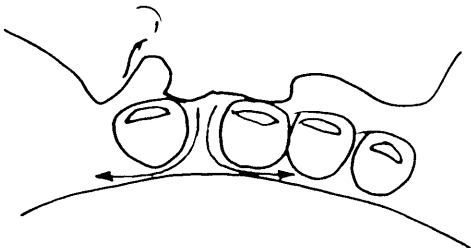


HOLD IT LIKE THIS...

BLOW HERE, VERY HARD...



AS YOU BLOW, LET GO
OF THE PAPER. IT
WILL STAY IN PLACE
FOR A FEW MOMENTS.



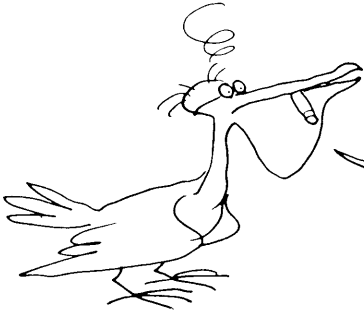
N.B.

Blow **HARD!!**

The Boss



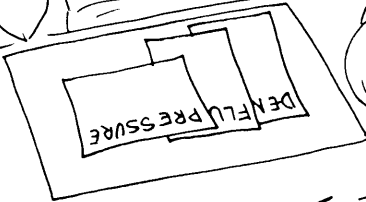
HOW ABOUT
COMING FOR A
FLIGHT ?



AFTER NOT I SEEN
TODAY, MATE, I'D RATHER
WALK !!!



FLUID, DENSITY, PRESSURE,
TEMPERATURE , REACTION,
BERNOULLI — I SHOULD HAVE
ALL THE WORDS I NEED
TO GET OFF THE GROUND.



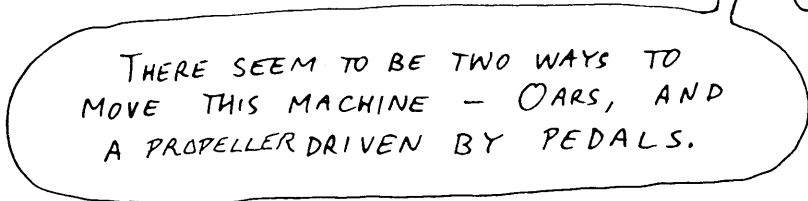
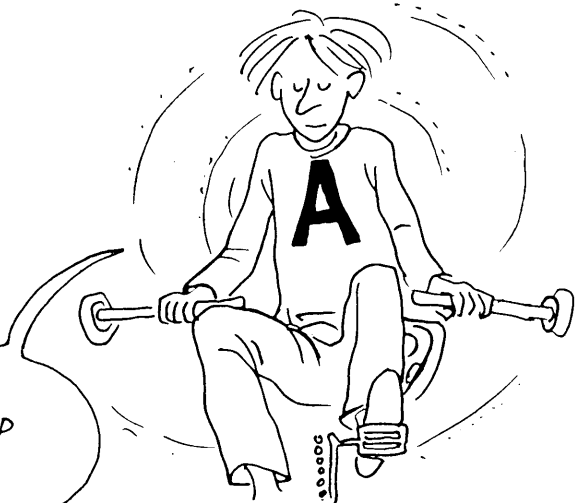
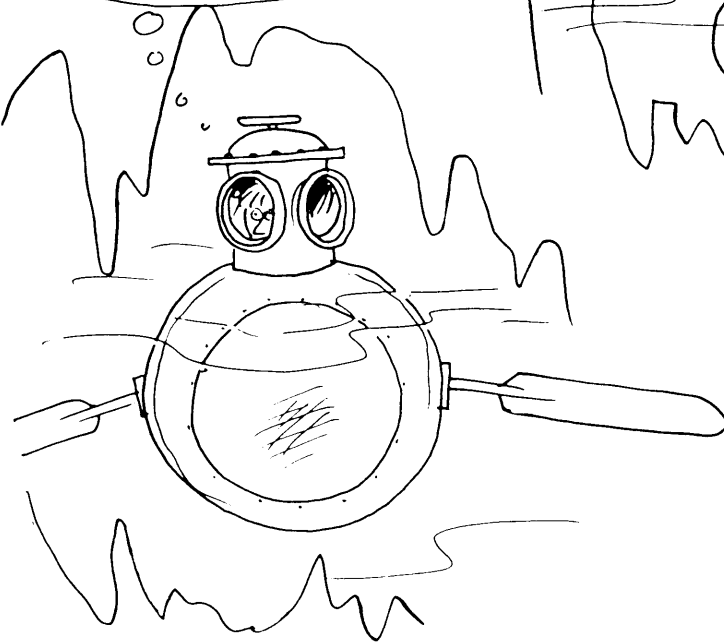
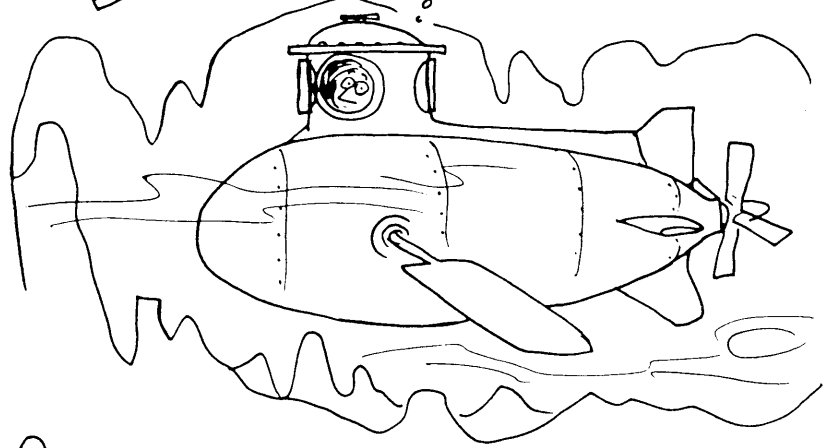
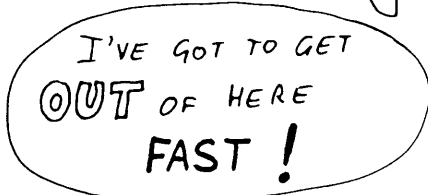
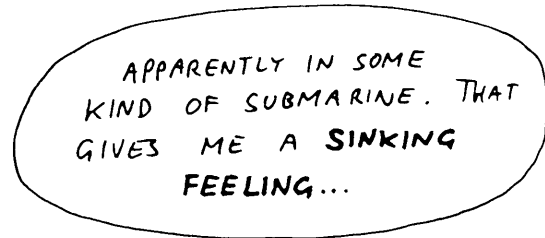
NO, THERE'S
ONE
MISSING.



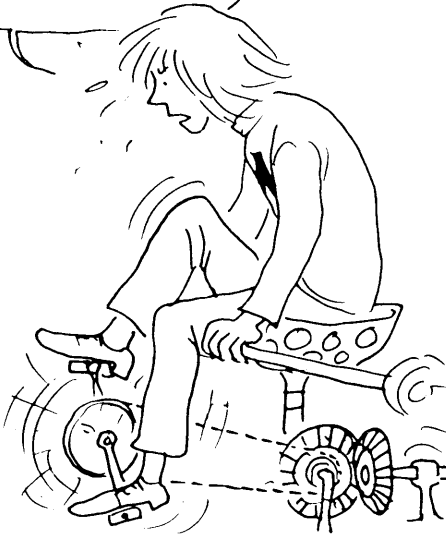
WHICH ?



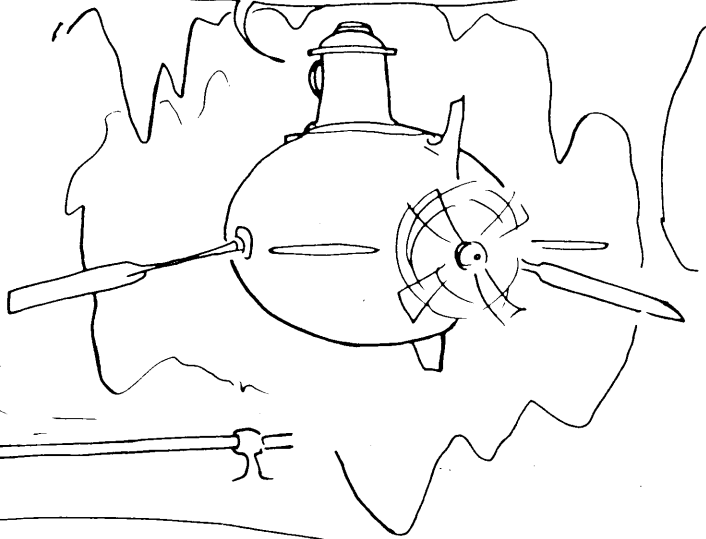
ARCHIBALD'S DREAM:



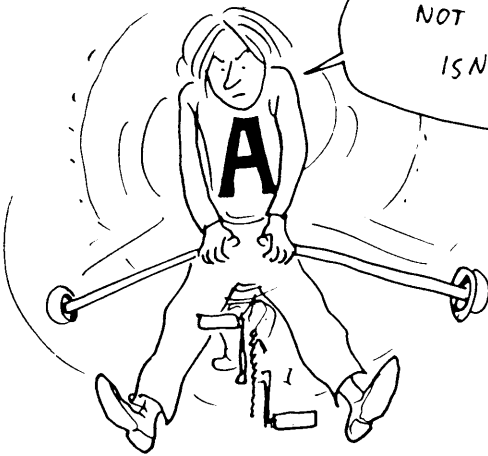
HELL, I'VE PEDALLED
FOR AN HOUR



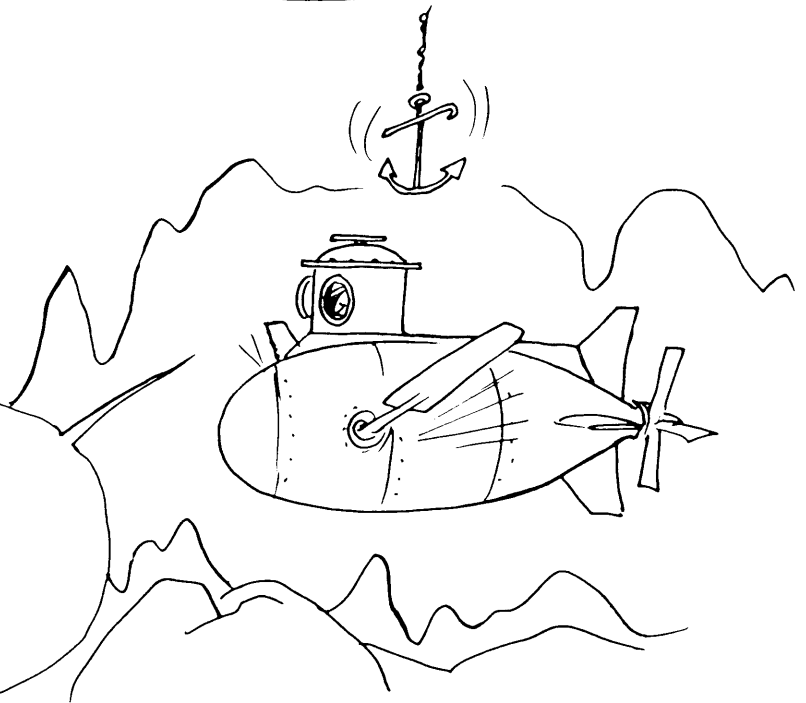
... AND I HAVEN'T
BUDGED A MILLIMETER !



LET'S TRY THE OARS ... **THEY'RE**
NOT DOING ANYTHING EITHER. THERE
ISN'T EVEN ANY **RESISTANCE !**

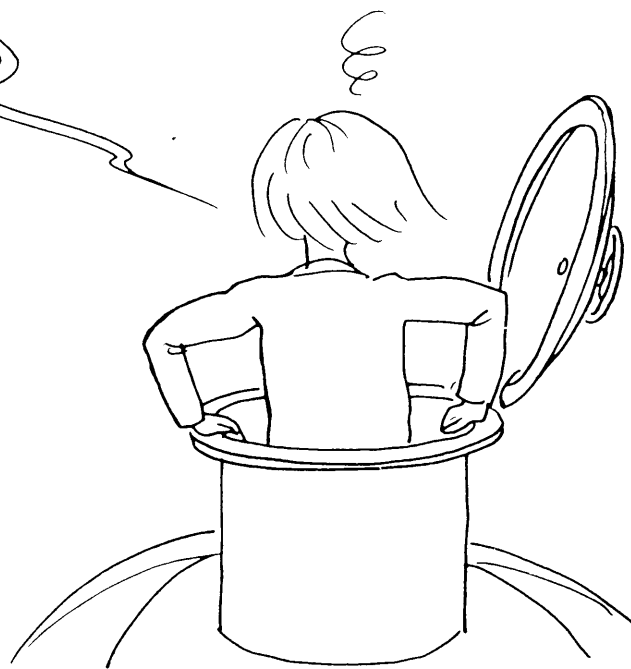
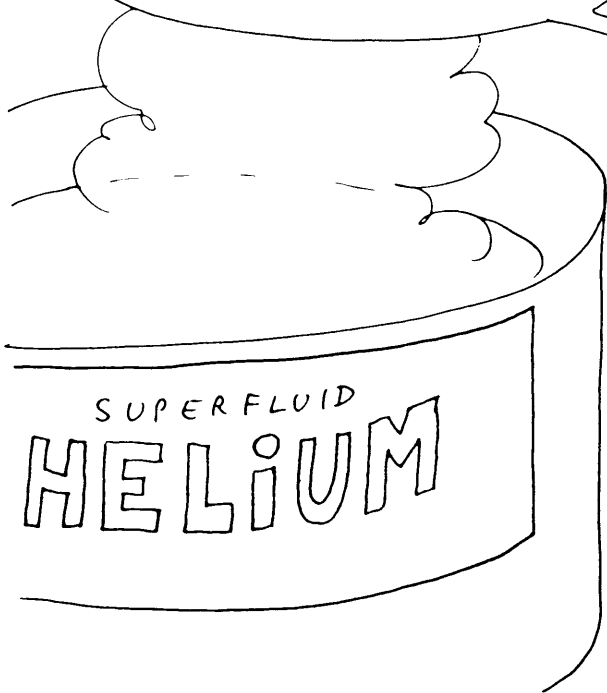


AM I IN A VACUUM ?
NO, THE SUBMARINE
WOULDN'T FLOAT...





BY ALL THE
WIND-DEVILS OF HELL,
SOPHIE - WHAT'S BEEN
GOING ON ?





YOU WERE JUST IN SOME **SUPERFLUID** HELIUM. REMEMBER WHAT HAPPENED IN THE SANDBOX? THE FRICTION OF THE GRAINS OF SAND AGAINST EACH OTHER WAS SO GREAT THAT THE SAND ONLY FLOWED WITH DIFFICULTY.

HERE IT'S THE OPPOSITE. BELOW A CERTAIN **VERY** LOW TEMPERATURE, THE FLUIDITY OF HELIUM BECOMES **INFINITE**, AND THERE IS NO FRICTION AT ALL.



BUT WHAT'S FRICTION GOT TO DO WITH ROWING, FLYING, OR PROPELLING YOURSELF WITH A PROPELLER?



YOU HAD THE IDEA, IN A WAY, WITH YOUR UMBRELLA. TO GET SUPPORT FROM THE AIR YOU HAVE TO GRAB HOLD OF IT.



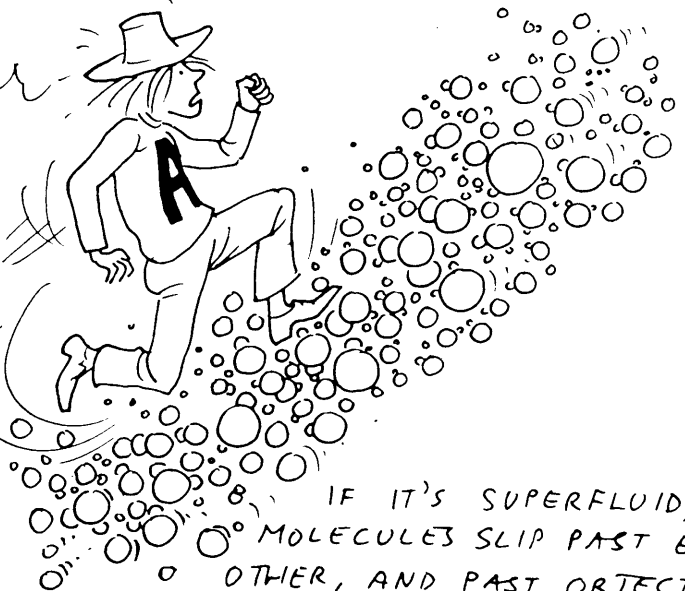
IF THE AIR WERE **SUPERFLUID**, YOUR PARACHUTE WOULDN'T BE ANY USE. WORSE - IT WOULDN'T OPEN, AND YOU'D FALL LIKE A STONE.

THE FIRST CREATURE WHO TRIED TO REACH FOR THE SKY QUICKLY FOUND OUT THAT ONE WAY OR ANOTHER, IT WOULD HAVE TO GRAB THE AIR...

SO THE FLIGHT OF A HEAVIER-THAN-AIR DEVICE IS LIKE AN ENDLESS ATTEMPT TO GAIN A HOLD ON SOMETHING SO TENUOUS THAT IT ALWAYS SLIPS FROM YOUR GRASP.



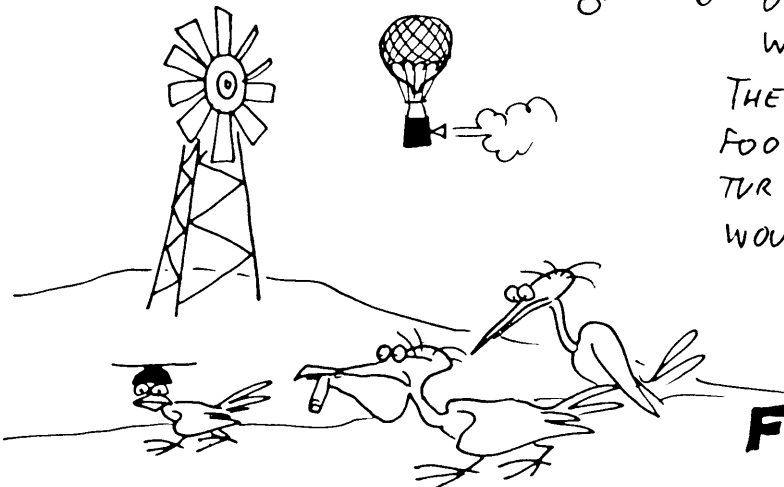
SO YOU HAVE TO FIND SOME WAY TO GET SUPPORT FROM SUCH A MEDIUM.



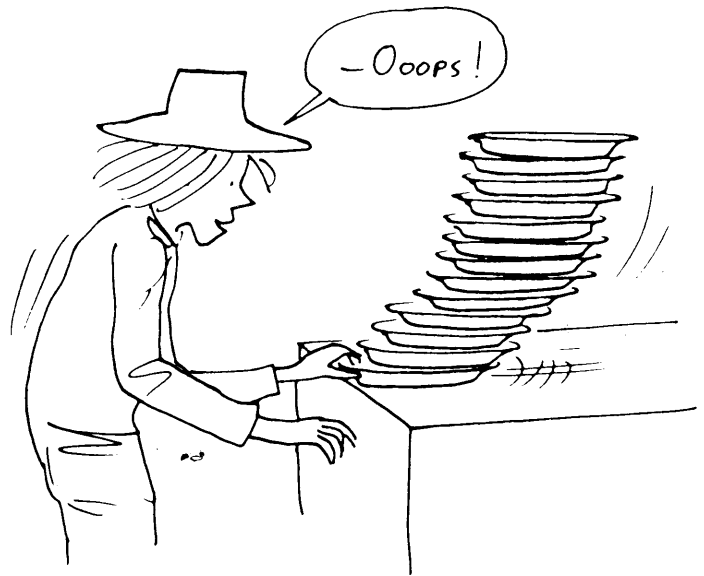
IF IT'S SUPERFLUID, THE MOLECULES SLIP PAST EACH OTHER, AND PAST OBJECTS, WITH NO FRICTION.

THE BIRDS WOULD HAVE TO GO ON FOOT, WINDMILLS WOULDN'T TURN, AND AERIAL TRANSPORT WOULD HAVE TO BE ACHIEVED USING BALLOONS WITH REACTION MOTORS.

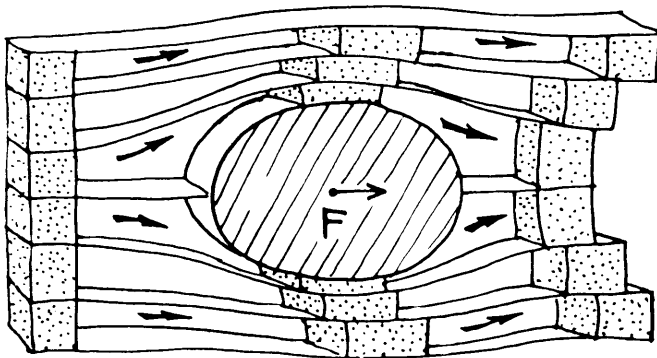
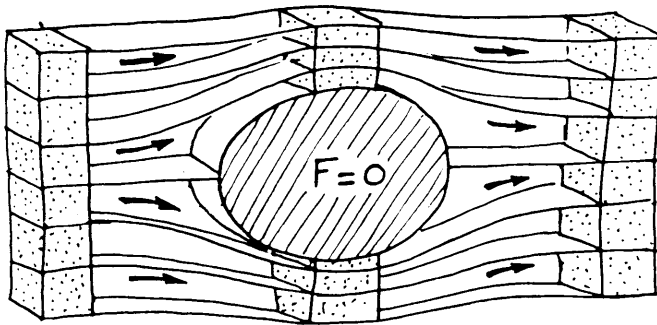
FLYING THUS DEPENDS ON GASEOUS FRICTION.



VISCOUS FLUIDS



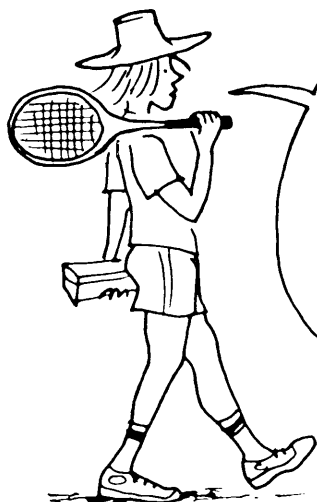
LIKE THESE PLATES, THE SUPERIMPOSED LAYERS OF GAS DO NOT SLIDE OVER EACH OTHER WITHOUT FRICTION.



I MAGINE A FIXED OBJECT IN A STREAM OF GAS MOLECULES, WHICH WE CAN REPRESENT BY LITTLE CUBICAL BOXES.

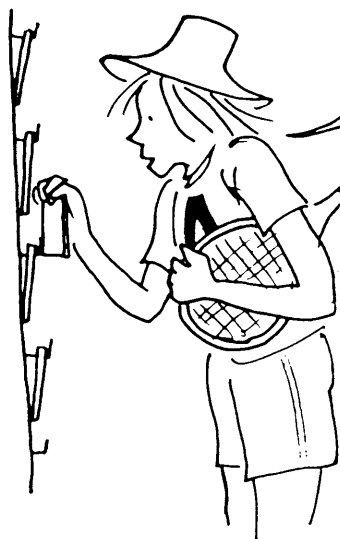
- IN THE ABSENCE OF ANY FRICTION, AFTER CIRCUMNAVIGATING THE OBJECT, THE MOLECULES END UP PILED ON TOP OF EACH OTHER LIKE THEY WERE AT THE START.
- IN CONTRAST, FRICTION SLOWS DOWN MOLECULES THAT PASS CLOSE TO THE OBJECT DOWNSTREAM, THE BOXES ARE SHIFTED, THE OBJECT SLOWS THE GAS DOWN, AND CONVERSELY THE GAS EXERTS A FORCE F ON THE OBJECT:

FRICTIONAL DRAG.



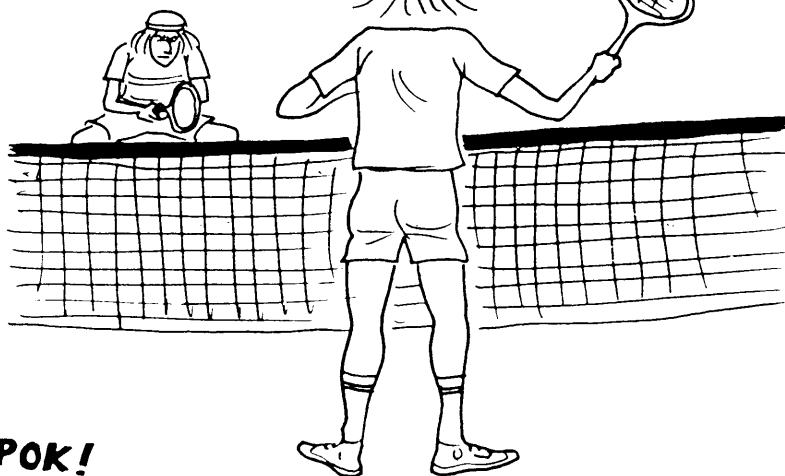
IT'S ALL TOO COMPLICATED FOR ME.
I THINK I'LL RELAX A BIT AND PLAY
SOME TENNIS. THE MECHANICS OF THAT,
AT LEAST, IS EASY. BALLISTICS. YOU
HIT THE BALL — BOOM! AND IF YOU'VE
CALCULATED IT CORRECTLY, IT LANDS
IN THE COURT.

SWERVICE GAME...



I'LL PUT MY NAME DOWN
FOR A GAME ... GOOD, HERE'S A
SPARE PLACE. BJÖRN BORG ...
DON'T KNOW HIM.

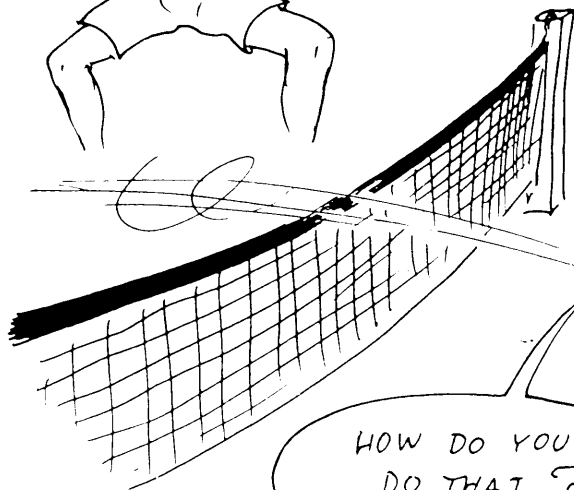
READY?



ЧПРК!



GOOD GRIEF - I HAVEN'T EVEN TOUCHED ONE YET! THIS GUY HAS A WAY OF LIFTING THE RACQUET WHEN HE SERVES THAT **OUGHT** TO MAKE THE BALL LIFT TOO...



IT DOESN'T. IT **DROPS**.

HOW DO YOU DO THAT?

EASY. I MAKE THE BALL SPIN LIKE THIS.



POK!

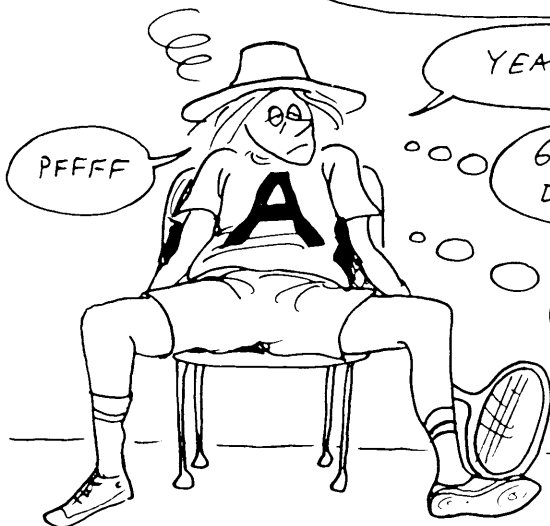
IT TENDS TO DROP. THAT LETS ME HIT IT HARDER WITHOUT GOING OFF THE COURT.

YEAH, SURE.

PFFFF

6-0, 6-0 DOWN...

CLEAR AS MUD...



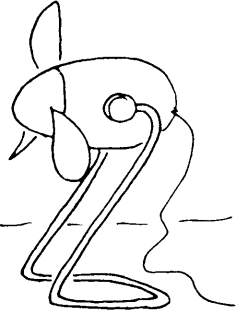
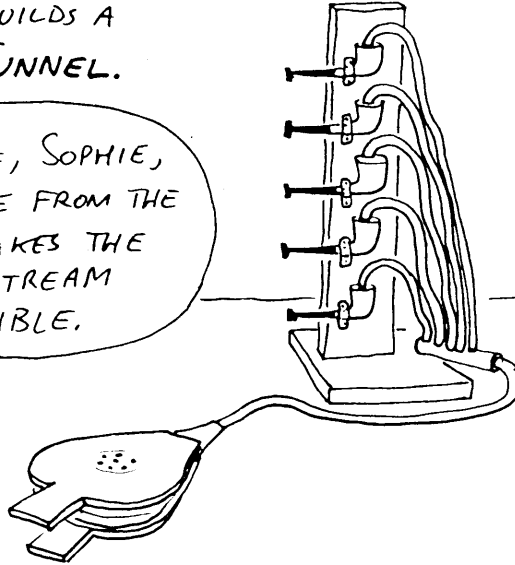


LET'S SEE. BORG SENT THE BALL FROM LEFT TO RIGHT IN THE PICTURE ON THE LAST PAGE. I'LL MAKE THE AIR HIT THE BALL FROM RIGHT TO LEFT - THAT OUGHT TO COME TO THE SAME THING.

ARCHIE BUILDS A WIND-TUNNEL.



YOU SEE, SOPHIE, THE SMOKE FROM THE PIPES MAKES THE AIRSTREAM VISIBLE.

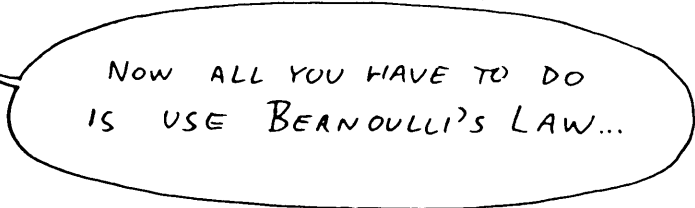
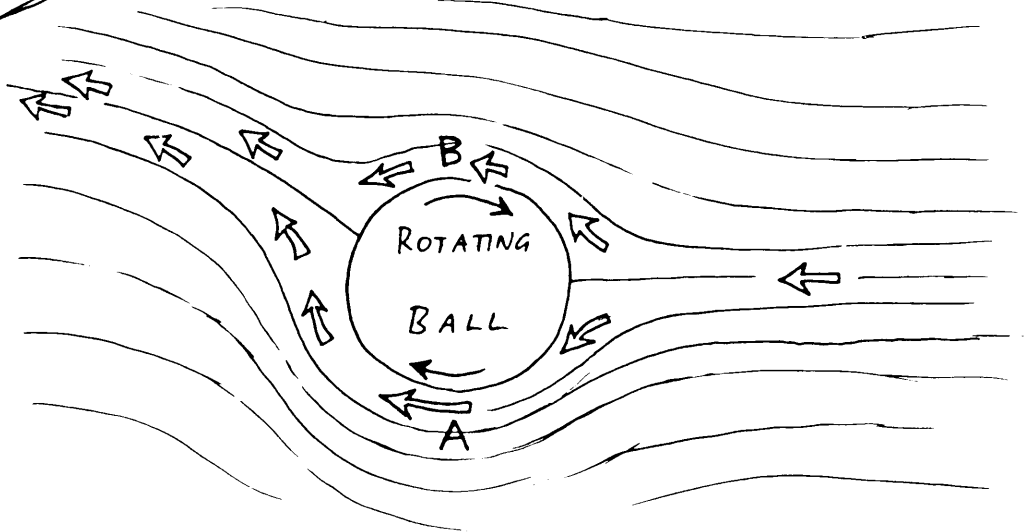
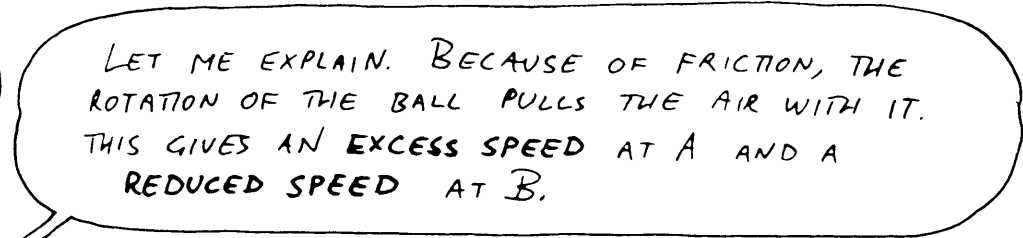
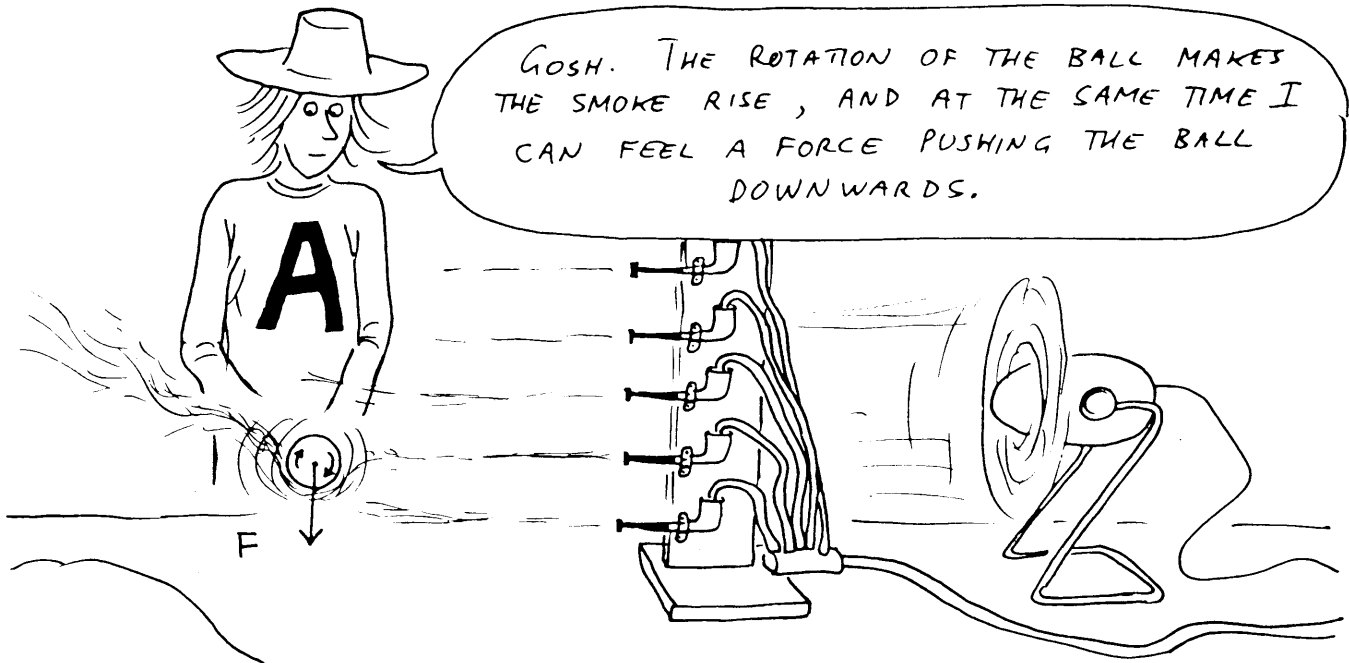


NOW ALL I NEED IS TO MAKE SURE THE BALL WILL ROTATE. THIS OUGHT TO DO IT...

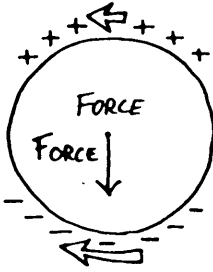


YES - THAT WHISKS IT AROUND BEAUTIFULLY!





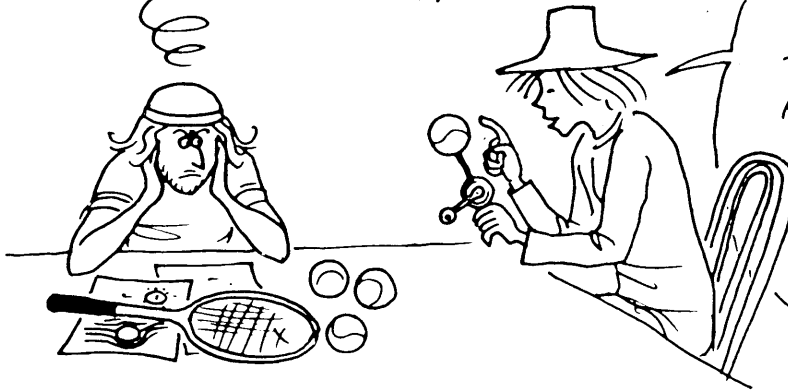
REDUCED SPEED - HIGH PRESSURE



AIR
SPEED

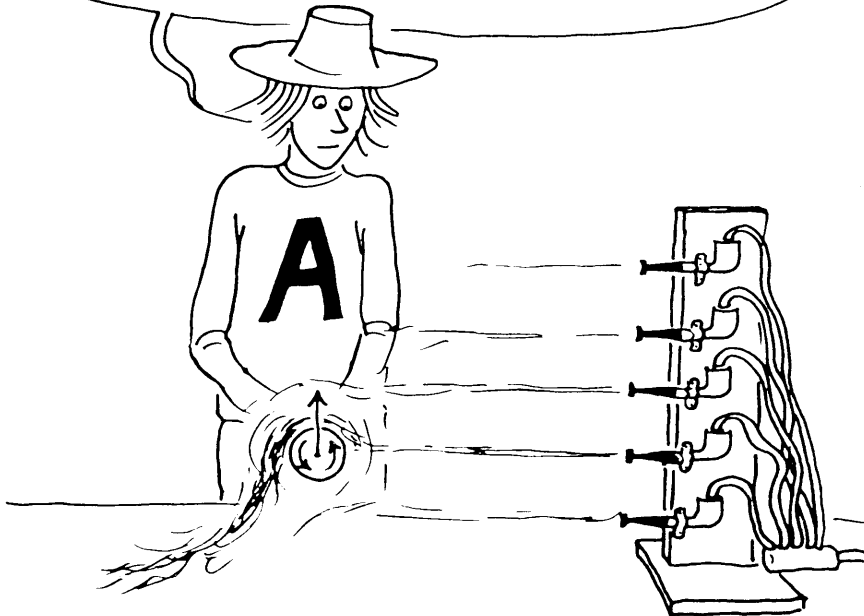
PRESSURE AND SPEED VARY INVERSELY.
SO UNDERNEATH THE PRESSURE IS **LOW**,
ON TOP IT IS **HIGH**. FROM THIS IT'S CLEAR
IN WHICH DIRECTION THE AERODYNAMIC
FORCE ACTS !

EXCESS SPEED - LOW PRESSURE



NOW THAT ONLY HAPPENS
BECAUSE OF FRICTION WITH
THE BALL. IN A SUPERFLUID
ATMOSPHERE, WITHOUT FRICTION,
YOU WOULDN'T BE **ABLE**
TO MAKE A TENNIS-BALL
SWERVE.

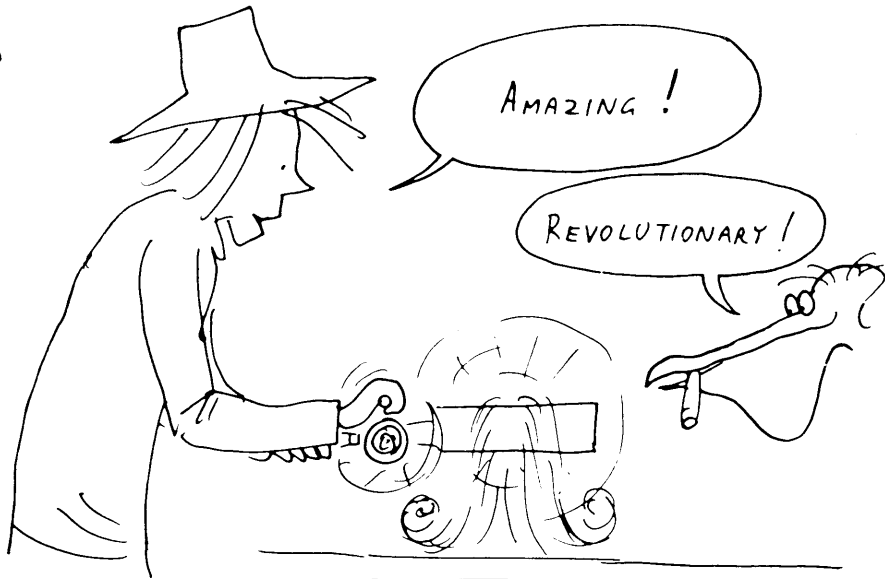
HEY! IF I REVERSE THE DIRECTION
OF ROTATION, THE SMOKE IS BENT
DOWNWARDS, AND THE FORCE IS REVERSED.
THAT GIVES ME A **LIFT**.



WHAT WORKS WITH A
SPHERE ALSO WORKS
WITH A ROTATING
CYLINDER ?

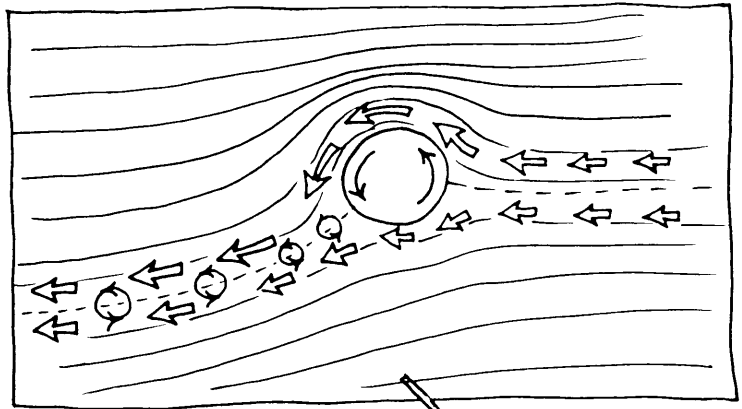
UH-HUH !

THE FLETTNER ROTOR



LADIES, GENTLEMEN, AND OTHERS - LET US LOOK MORE CLOSELY IN THE **WAKE** OF THIS DISCOVERY.

THE ROTATION OF THE CYLINDER PRODUCES DIFFERENT SPEEDS IN THE FLOWS OVER THE TOP AND UNDERNEATH.

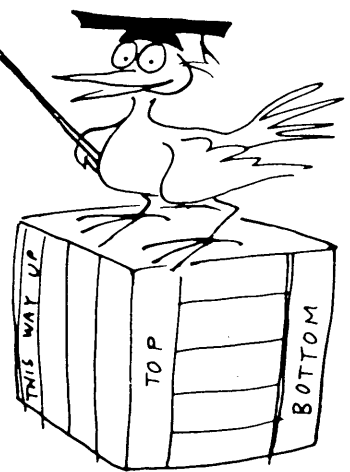


DOWNSTREAM FROM THE CYLINDER, ALTHOUGH THE TWO LAYERS OF AIR JOIN UP AGAIN, THEY RUB AGAINST EACH OTHER.

AS A RESULT:

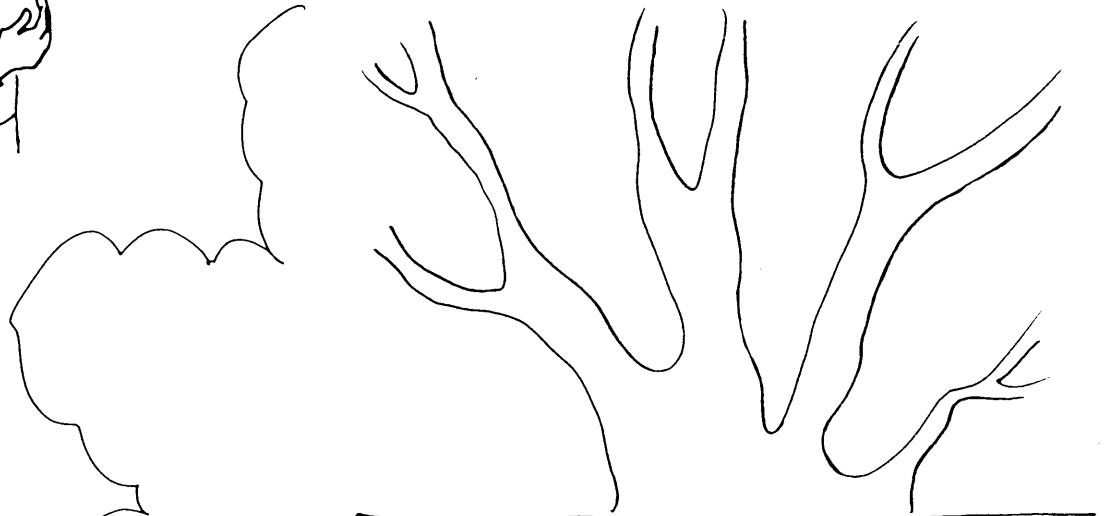
- a) TINY EDDIES FORM.
- b) THE DIFFERENCE IN SPEED IS PROGRESSIVELY DIMINISHED.

THERE IS A PRESSURE DIFFERENCE BETWEEN THE TOP OF THE LAYER AND THE BOTTOM, RELATED TO THE DIFFERENCE IN THE SPEEDS (BERNOULLI). THIS IS WHY THE AIRSTREAM IS CURVED, DOWNSTREAM OF THE ROTOR.





BY ROTATING A CYLINDER IN THE AIR, I'VE
MANAGED TO GET SOME **LIFT**. THAT GIVES
ME AN IDEA! I OUGHT TO BE ABLE TO
MAKE A **FLYING MACHINE**.



KLONK
KLONK
SWWWWIIII

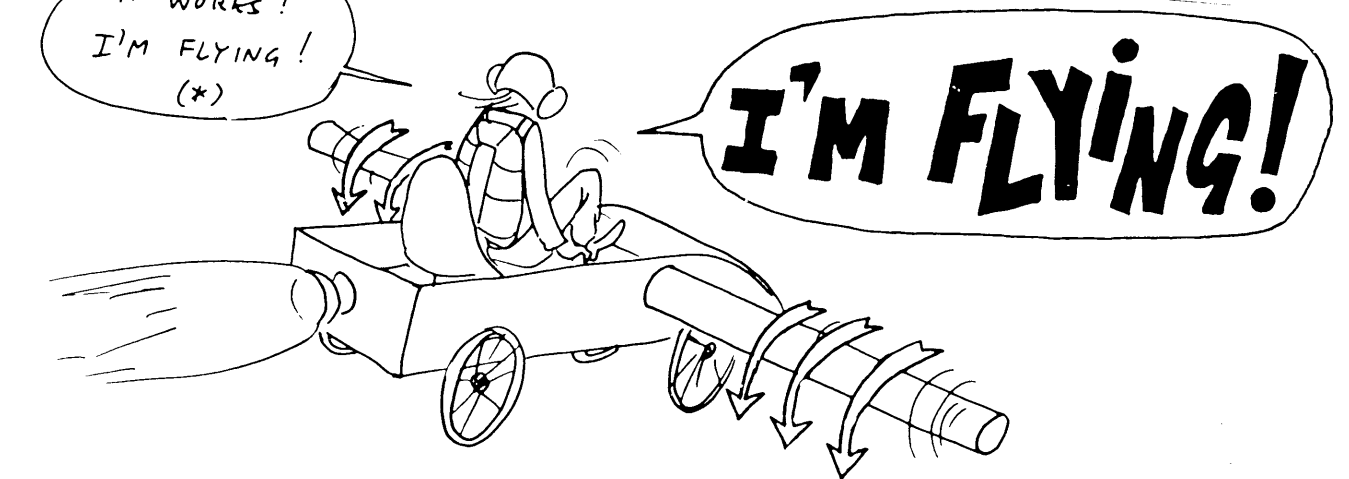
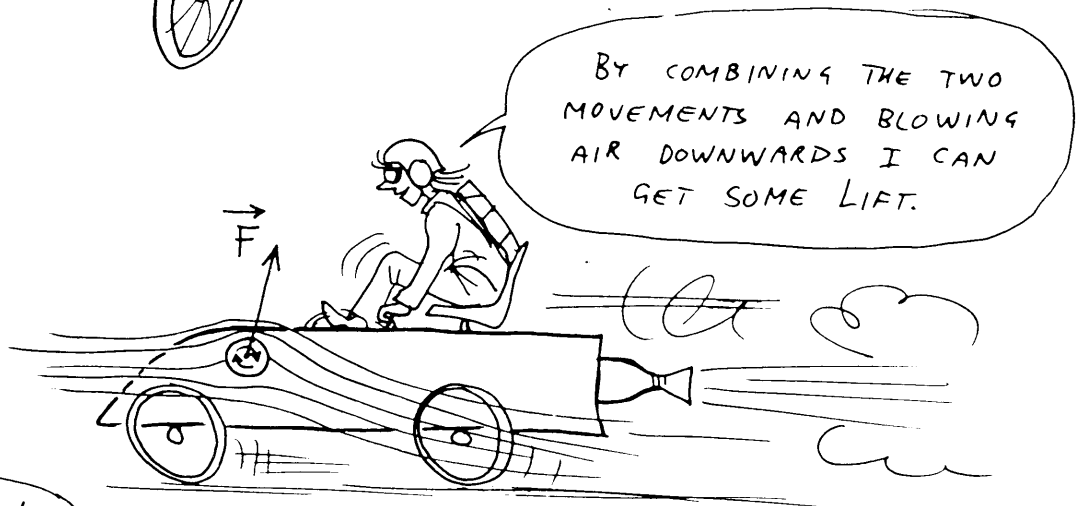
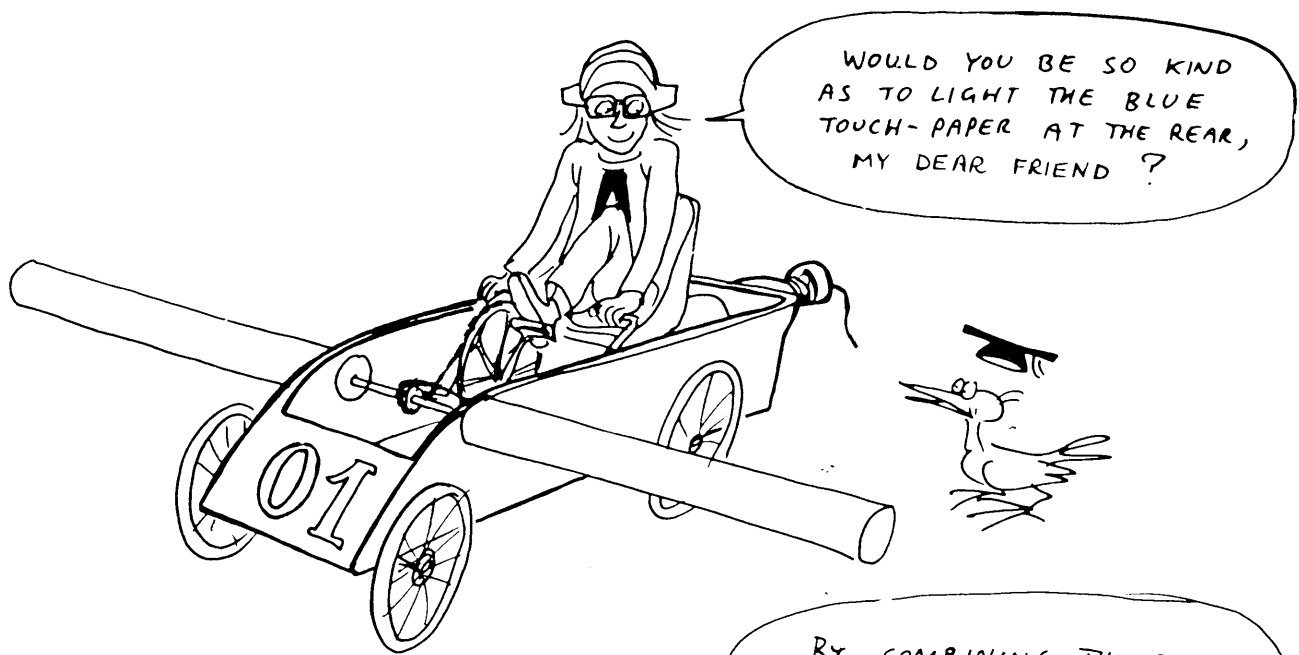
WOT'S 'E
MUCKIN' ABART
WIV NOW?



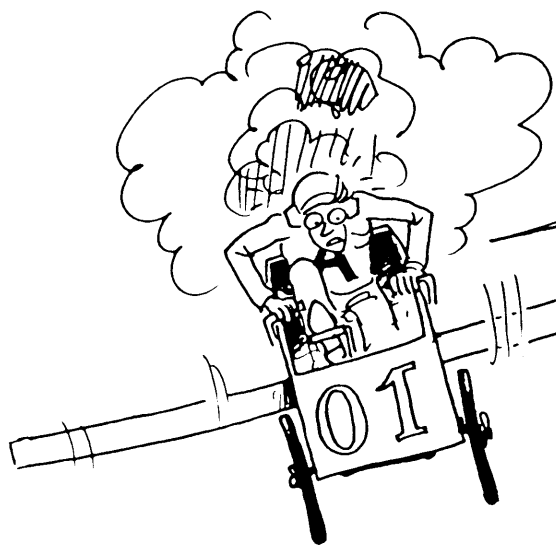
IT LOOKS
FIENDISHLY
COMPLICATED.

I'M TRYING
TO ADAPT MY
REACTION MOTOR.





(*) IF THE POWER IS HIGH ENOUGH, IT ACTUALLY WORKS VERY WELL !

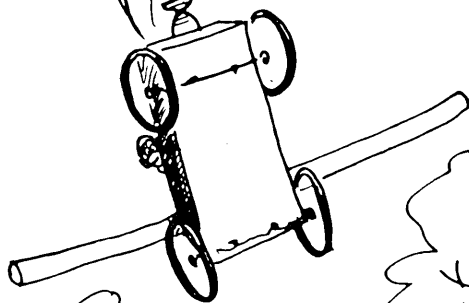


YIKES! WHAT'S HAPPENING?
I'M GOING INTO A
DIVE!

ONLY TO BE EXPECTED,
ARCHIE. YOU MAKE THE AIR
TURN, SO THE MACHINE HAS
A TENDENCY TO TURN THE
OTHER WAY.

IT'S THE PRINCIPLE
OF **ACTION** AND
REACTION.

THE PRINCIPLE
OF **WHAT?**



OH, ARCHIE - **WHY** DIDN'T YOU ASK ME
FIRST? THERE'S A MUCH SIMPLER WAY - BUT
YOU ALWAYS HAVE TO DO IT ON YOUR OWN, DON'T
YOU? COME ON, THE COFFEE'S READY.





AH, THOSE
PRECIPITATE MEN
IN THEIR
FLYING-MACHINES!

IT'S FUNNY, WHAT
YOU CAN SEE IN A
CUP OF COFFEE.



IF I MOVE THE
SPOON VERY GENTLY,
I CAN ONLY FEEL A
TINY AMOUNT OF
RESISTANCE, DUE
TO FRICTION...



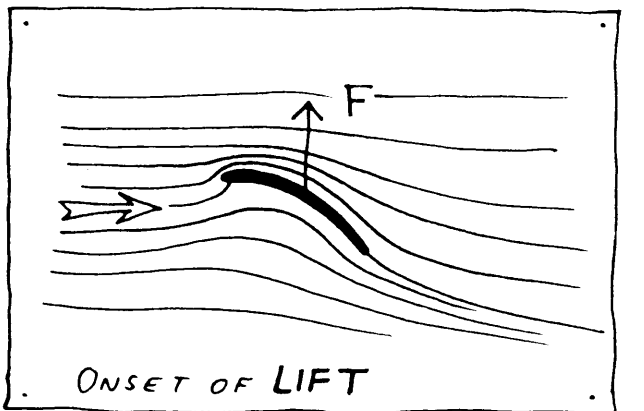
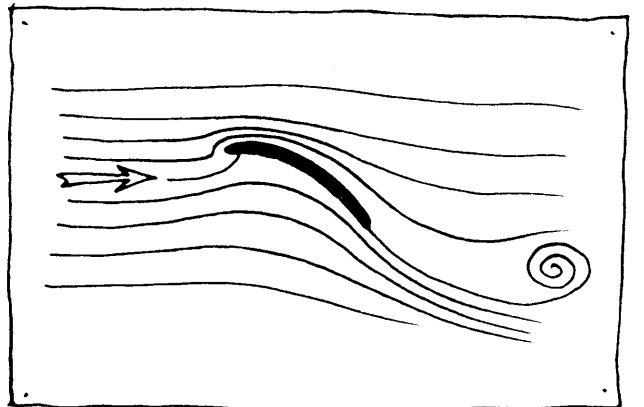
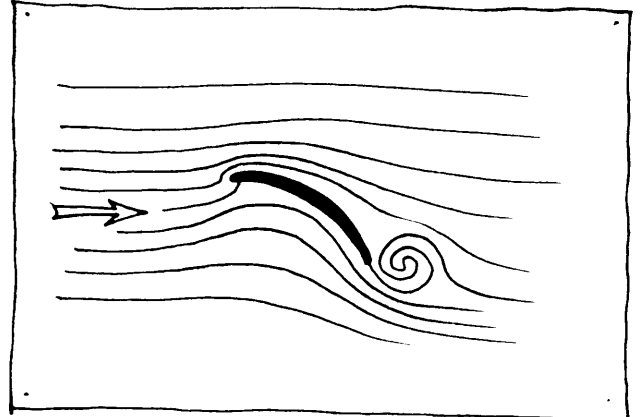
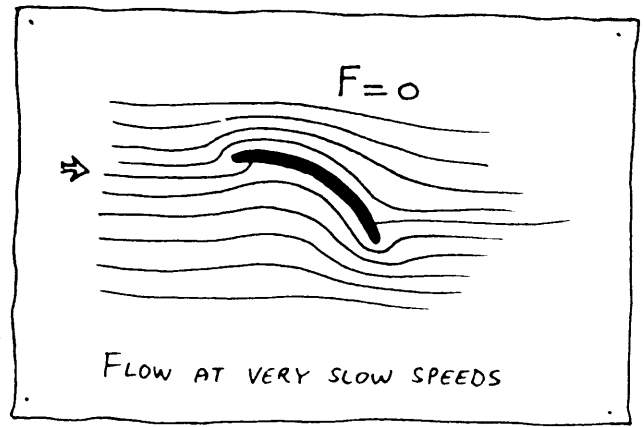
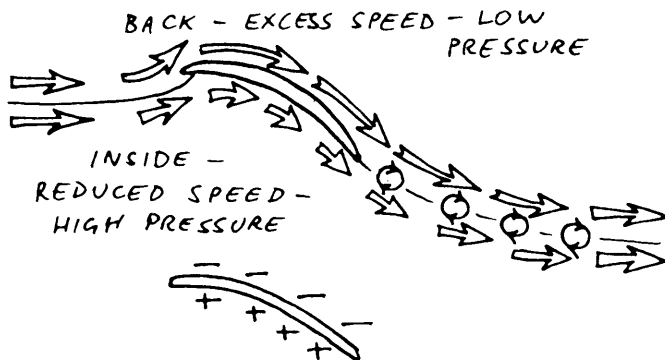
... BUT IF I
MOVE IT QUICKLY,
AN EDDY BREAKS
AWAY FROM IT.

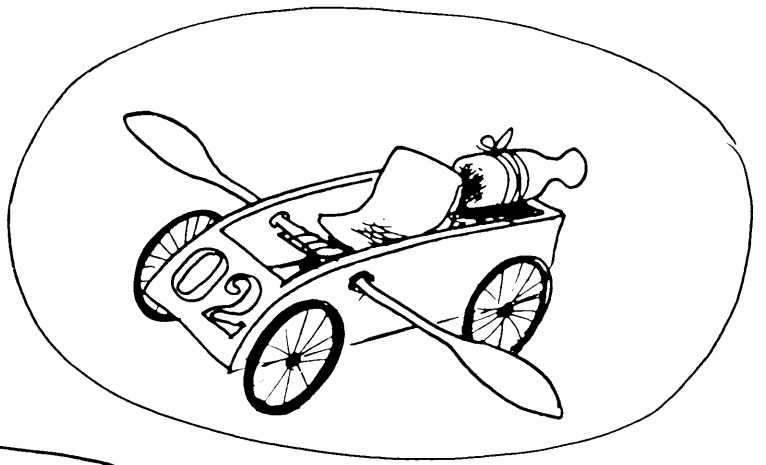




IN THESE DRAWINGS YOU CAN SEE HOW THE FLOW AROUND THE SPOON CHANGES AS IT GETS AWAY FROM LOWER SPEEDS.

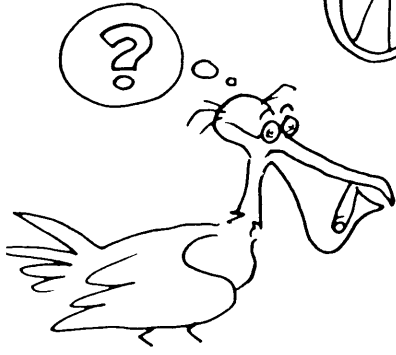
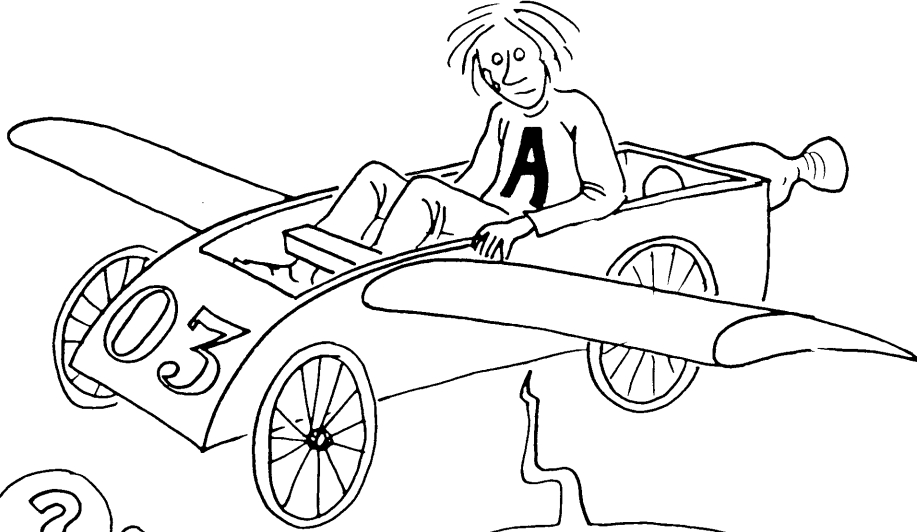
AN EDDY DETACHES ITSELF, AND THIS ESTABLISHES A SYSTEM OF EXCESS SPEED ACROSS THE BACK (TOP) AND REDUCED SPEED ROUND THE INSIDE (BOTTOM).



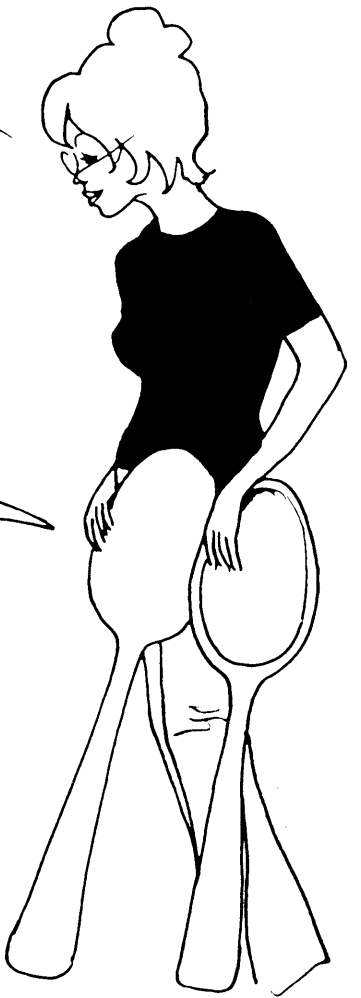


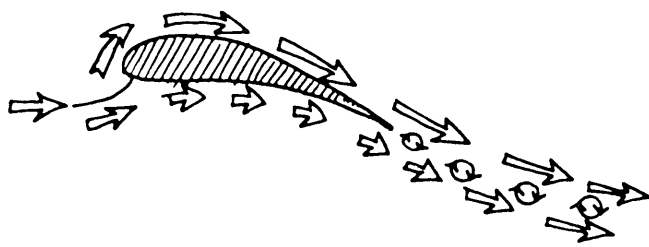
TERRIFIC! I'LL MAKE A
FLYING SPOONMOBILE !!

WINGS ARE
IMPROVED SPOONS,
ARCHIE.

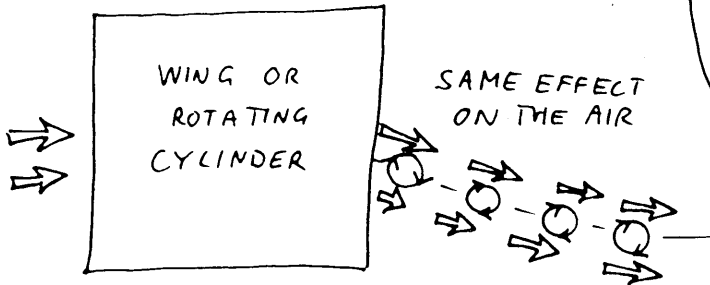


SURE. BUT WHERE'S
THE ROTATION?

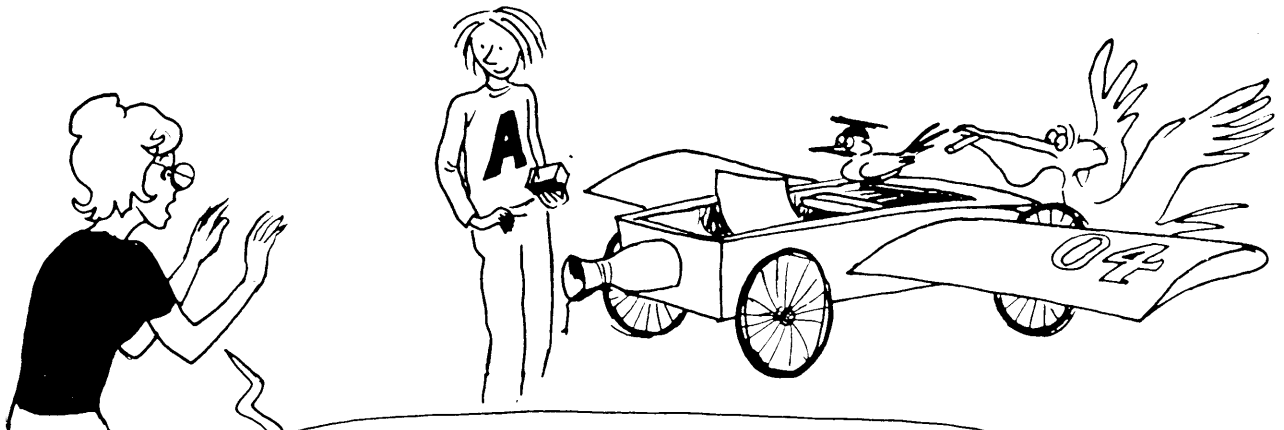




DOWNSTREAM OF
THE WING YOU FIND
THE SAME SYSTEM OF
TINY EDDIES AS BEHIND
THE ROTATING CYLINDER.
SO YOU CAN THINK OF A
WING AS A **FIXED**
ROTOR.



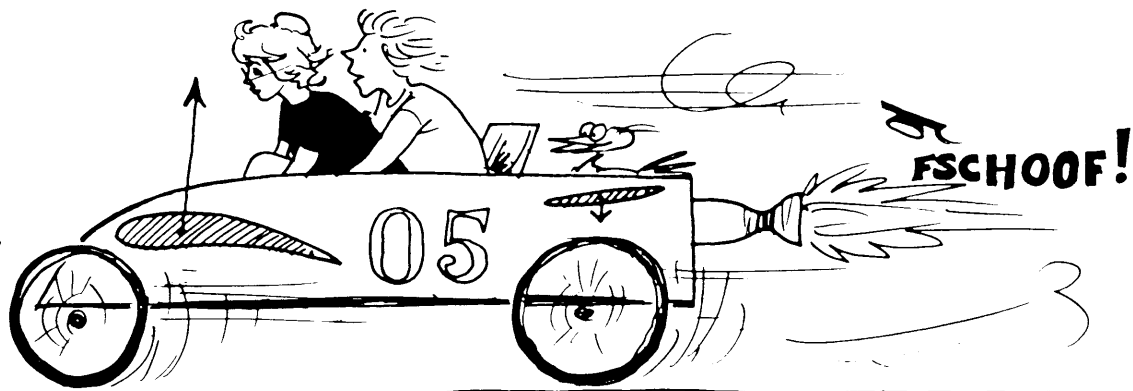
SAME EFFECT
ON THE AIR



WAIT! YOU'LL BREAK YOUR NECK YET!
YOU'VE STILL GOT THE SAME PROBLEM AS
BEFORE. BECAUSE THE MACHINE SETS THE
AIR ROTATING, IT TENDS TO **DIVE!**

YOU NEED TO ADD
A **TAIL PLANE**.

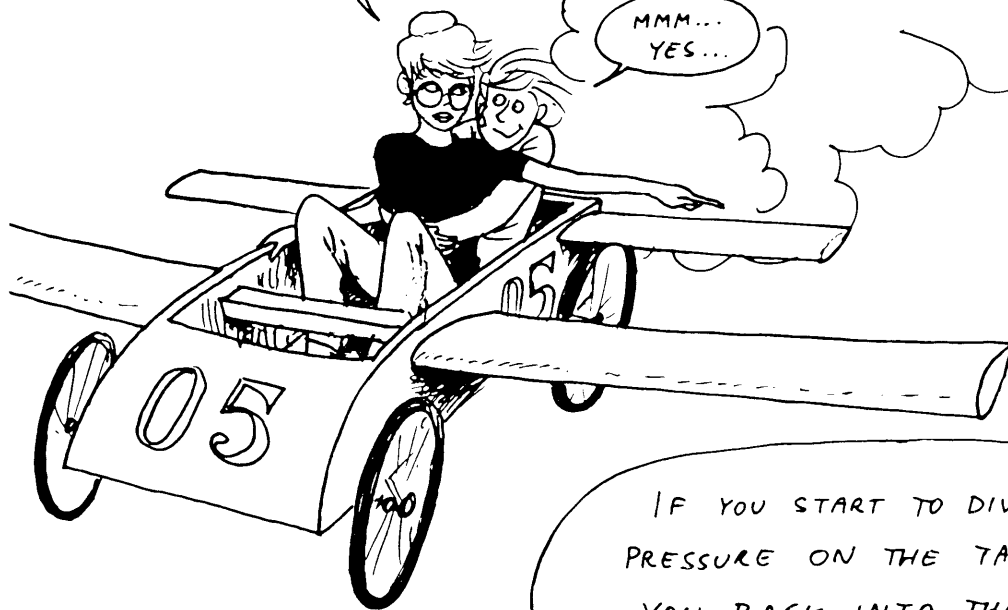




THE TAILPLANE IS A LITTLE WING TILTED THE OTHER WAY, PRODUCING NEGATIVE LIFT AND PULLING THE TAIL DOWN. THAT PREVENTS THE AIRCRAFT FROM GOING INTO A DIVE.

LOOK, ARCHIE! IT'S AN AUTOSTABLE SYSTEM!

MMM...
YES...



IF YOU START TO DIVE, THE PRESSURE ON THE TAILPLANE PUSHES YOU BACK INTO THE LINE OF FLIGHT.

THE SAME THING
HAPPENS IF YOU **CLIMB**.



ARCHIE! YOU'RE
NOT PAYING
ATTENTION!

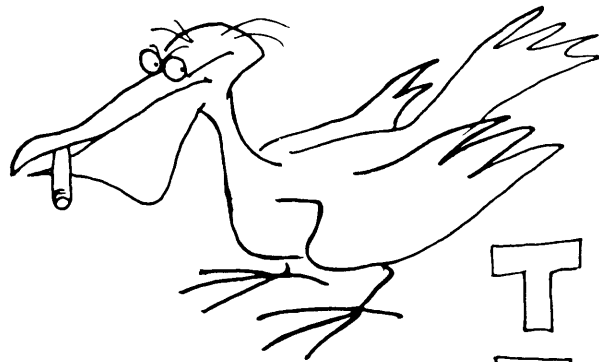
I AM, I AM!
I'M HANGING ON
YOUR EVERY
WORD!

MY **WORD** SEEMS
TO HAVE BECOME
MISPLACED.

I REALLY DIG THIS
AUTOSTABLE FEELING!



AND THAT, O BEST BELOVED, IS 'OW
ARCHIE 'IGGINS GOT 'IS WINGS.
IN THE END IT WAS AS EASY AS
PIE IN THE SKY.
AND 'IS SCIENTIFIC URGES CAN
ONLY GROW WIV ALTITUDE...



THE
END