The Adventures of
Archibald Higgins
(Anselme Lanturlu)

THE SILENCE BARRIER

Jean-Pierre
Petit

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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:

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Jean-Pierre Petit **Gilles d'Agostini**

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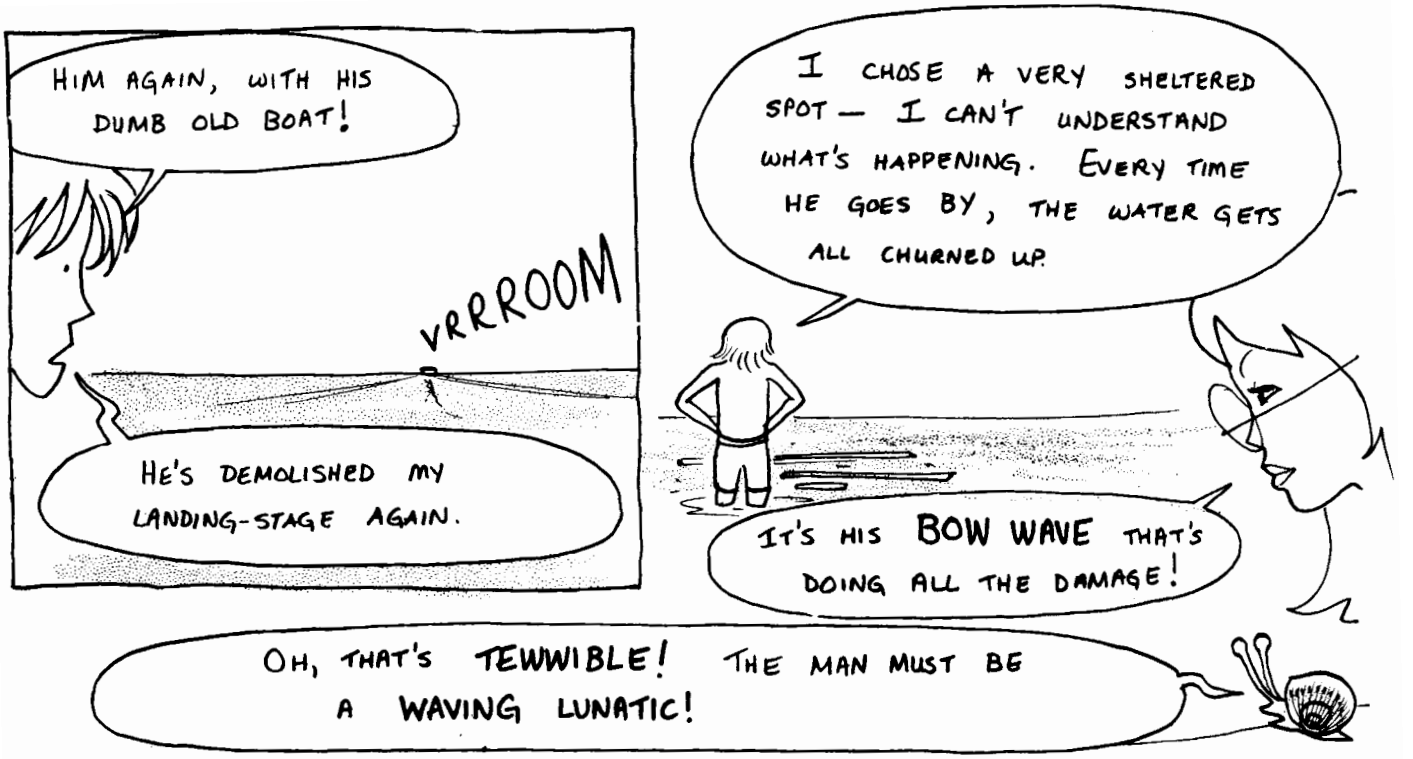
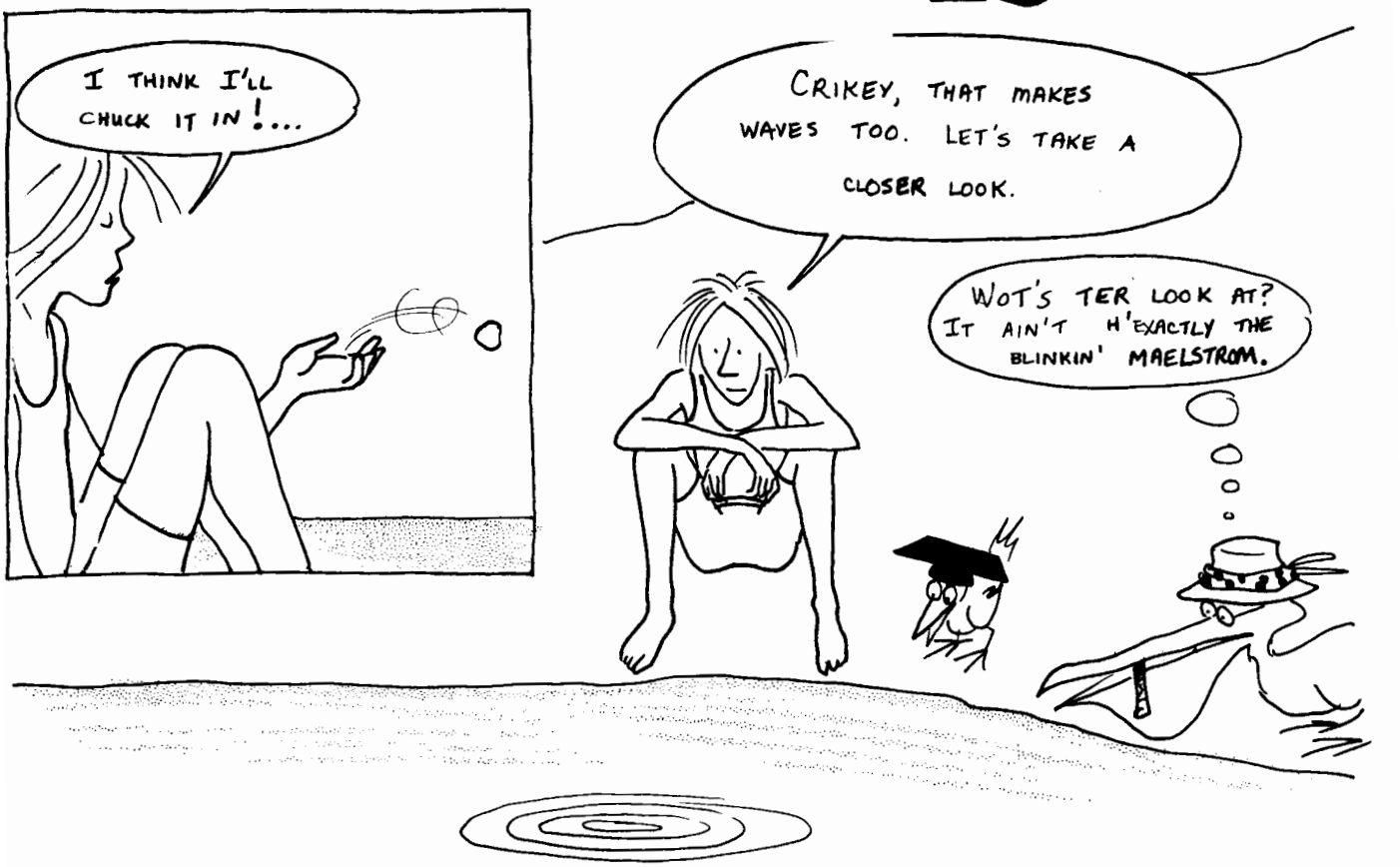
PROLOGUE

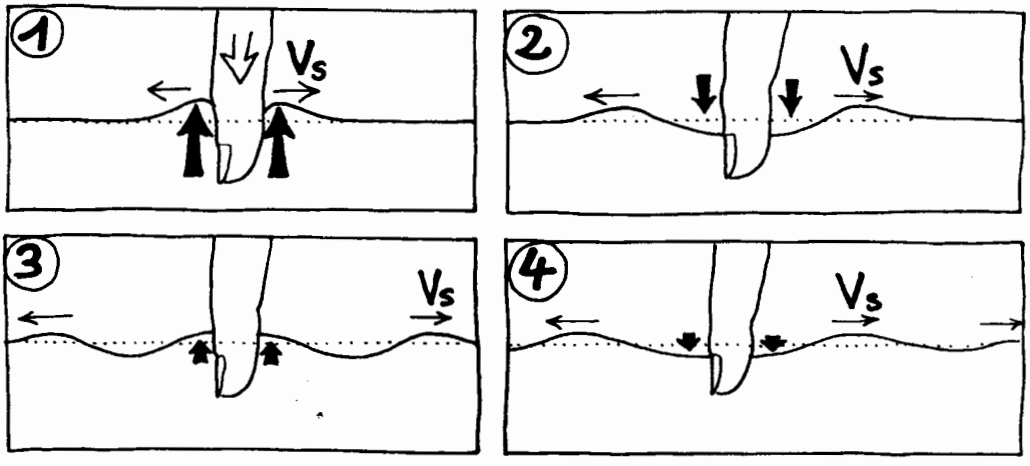

YOU CAN'T BEAT A NICE VACATION AT THE BEACH.
YUR, IT AIN'T BAD.
ARCHIE SEEMS TO BE HAVING FUN...
YUR. 'E'S MUCKIN' ABAHT WIV SOMEFINK AGAIN...
I DO BELIEVE HE'S BUILDING A LANDING-STAGE.
GO, BABY, GO!!!
FASTER, GEORGE! IT'S SO EXCITING!
VRRROOOM
!!..
HI THERE, BUDDY!
HERE WE GO AGAIN!
OH, GEORGE, THIS IS REALLY LIVING!
VRRRROOOOOM



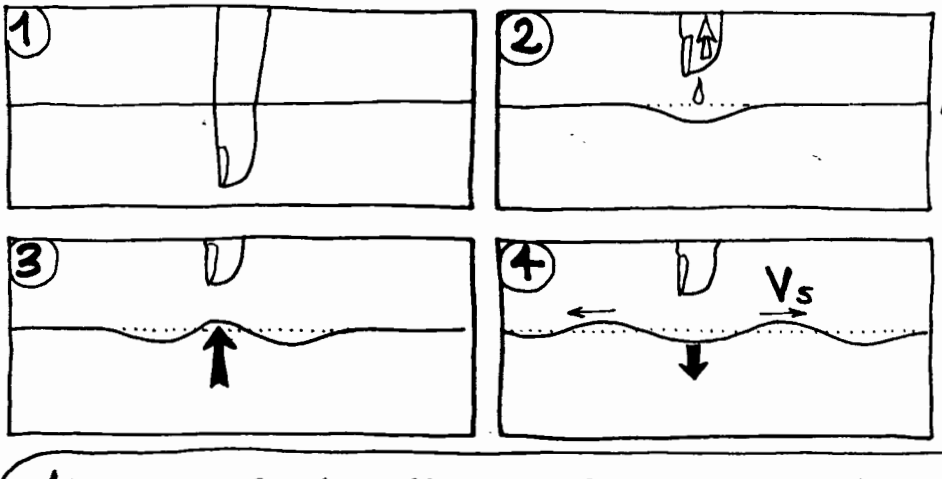
SURFACE WAVES



IF I STICK MY FINGER IN SUDDENLY, IT MAKES THE WATER NEARBY RISE TO FORM A SORT OF "SPARE TIRE." THE EXTRA THICKNESS LEADS TO OSCILLATIONS, WHICH ELIMINATE IT, FORMING CONCENTRIC **SURFACE WAVES.** THESE APPEAR TO TRAVEL AT A CONSTANT SPEED, WHICH I'LL CALL V_S; AND AS THEY MOVE, THEY SLOWLY DIE AWAY.



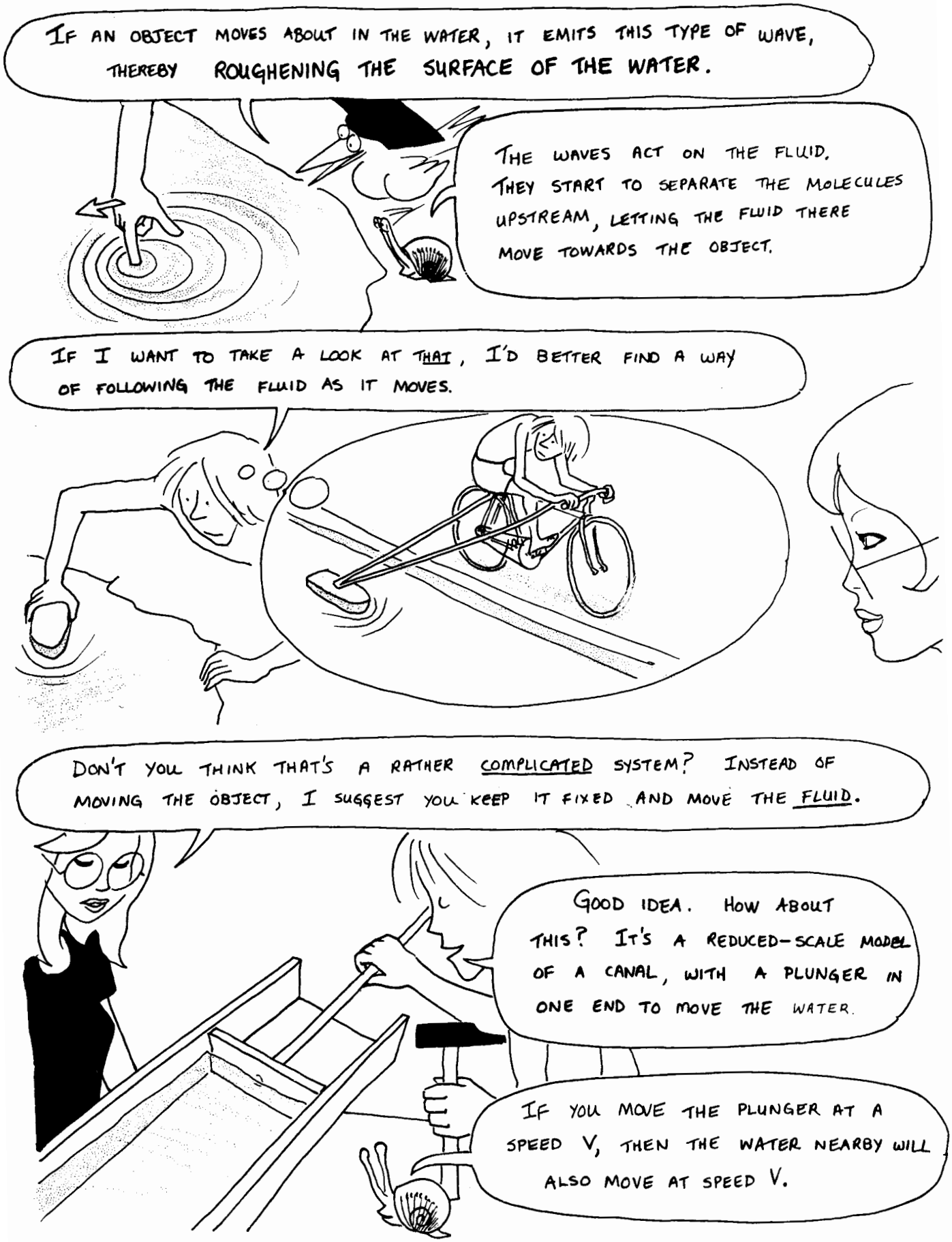
A SIMILAR EFFECT OCCURS IF, INSTEAD OF STICKING YOUR FINGER INTO THE WATER, YOU PULL IT OUT. AS A RESULT, THE LIQUID TENDS TOWARD A **FREE PLANAR SURFACE.**



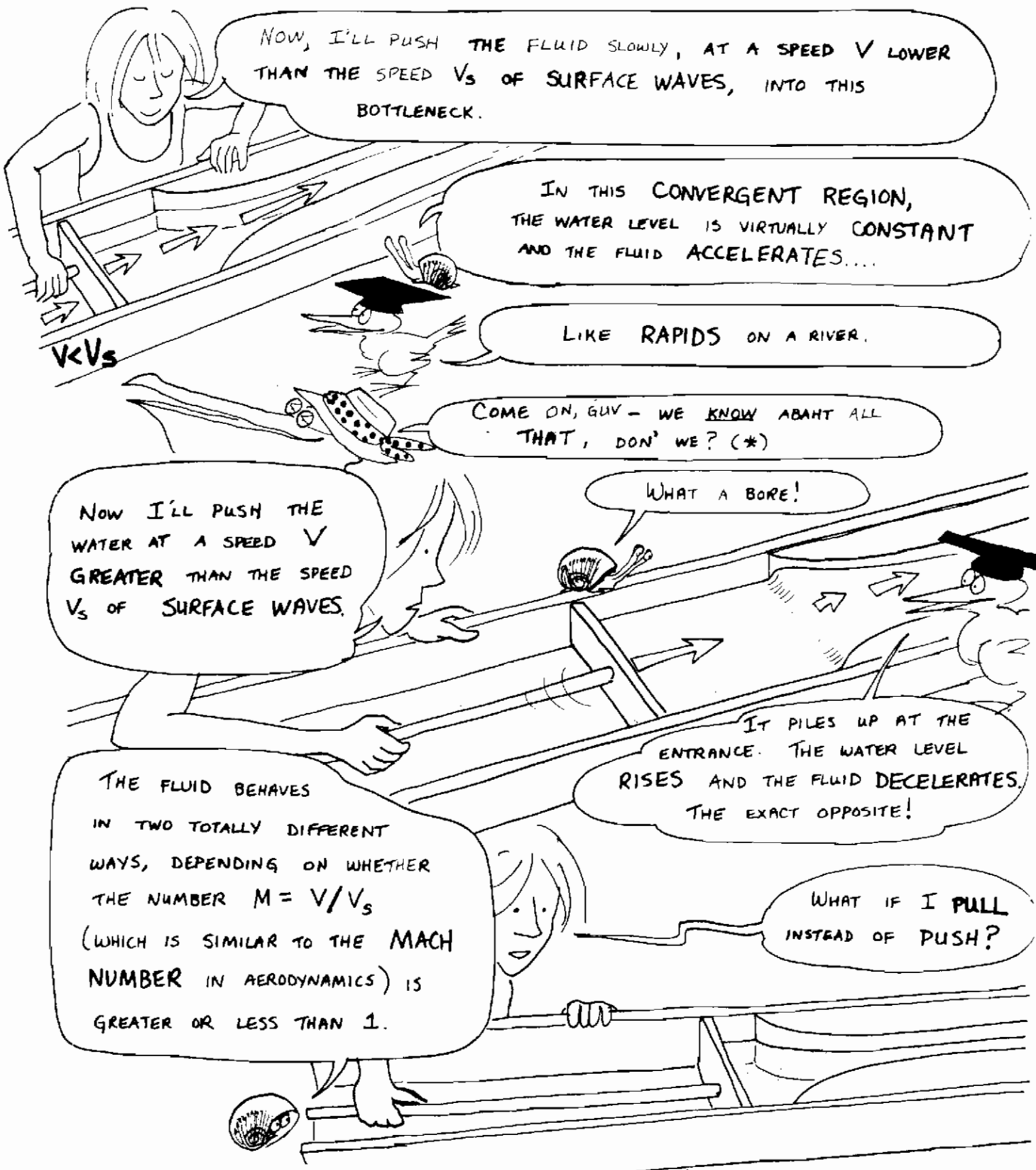
COR! BARFROOM PHYSICS!

AS THE WAVES PROPAGATE, THEY **SPREAD** THEIR ENERGY OVER AN INCREASING AREA.

AND SINCE ENERGY IS **CONSERVED,** THE HEIGHT - OR **AMPLITUDE** - OF THE WAVES MUST PROGRESSIVELY DECREASE.

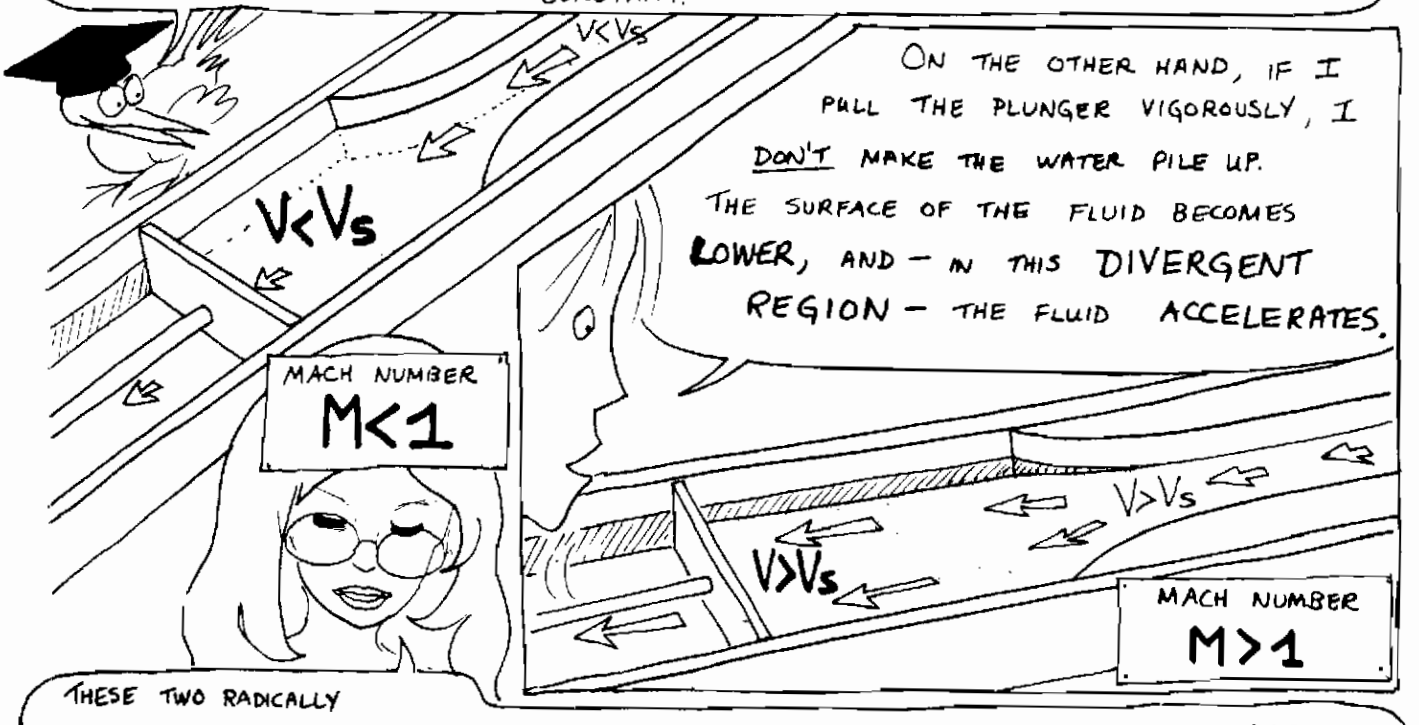

IF AN OBJECT MOVES ABOUT IN THE WATER, IT EMITS THIS TYPE OF WAVE, THEREBY ROUGHENING THE SURFACE OF THE WATER.
THE WAVES ACT ON THE FLUID. THEY START TO SEPARATE THE MOLECULES UPSTREAM, LETTING THE FLUID THERE MOVE TOWARDS THE OBJECT.
IF I WANT TO TAKE A LOOK AT THAT, I'D BETTER FIND A WAY OF FOLLOWING THE FLUID AS IT MOVES.
DON'T YOU THINK THAT'S A RATHER COMPLICATED SYSTEM? INSTEAD OF MOVING THE OBJECT, I SUGGEST YOU KEEP IT FIXED AND MOVE THE FLUID.
GOOD IDEA. HOW ABOUT THIS? IT'S A REDUCED-SCALE MODEL OF A CANAL, WITH A PLUNGER IN ONE END TO MOVE THE WATER.
IF YOU MOVE THE PLUNGER AT A SPEED V, THEN THE WATER NEARBY WILL ALSO MOVE AT SPEED V.

HUGONIOT'S RELATION



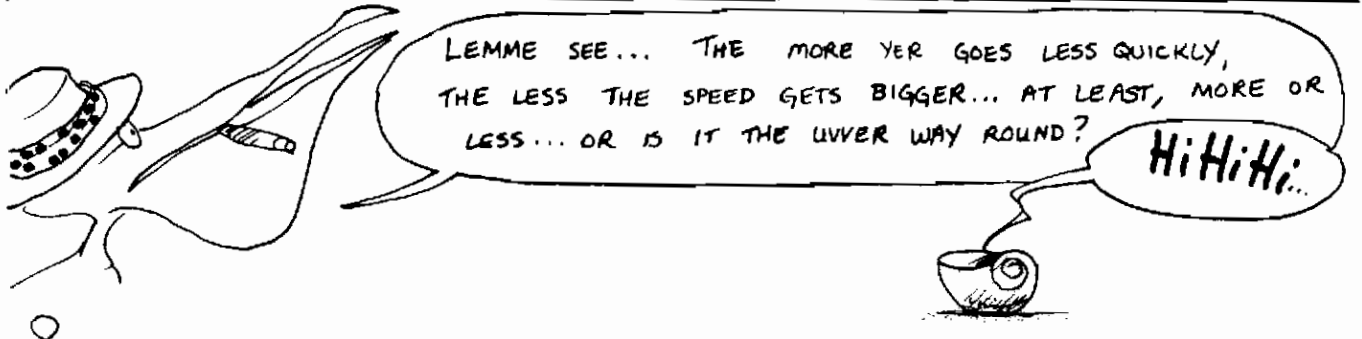
(*) SEE FLIGHT OF FANCY, SAME SERIES.

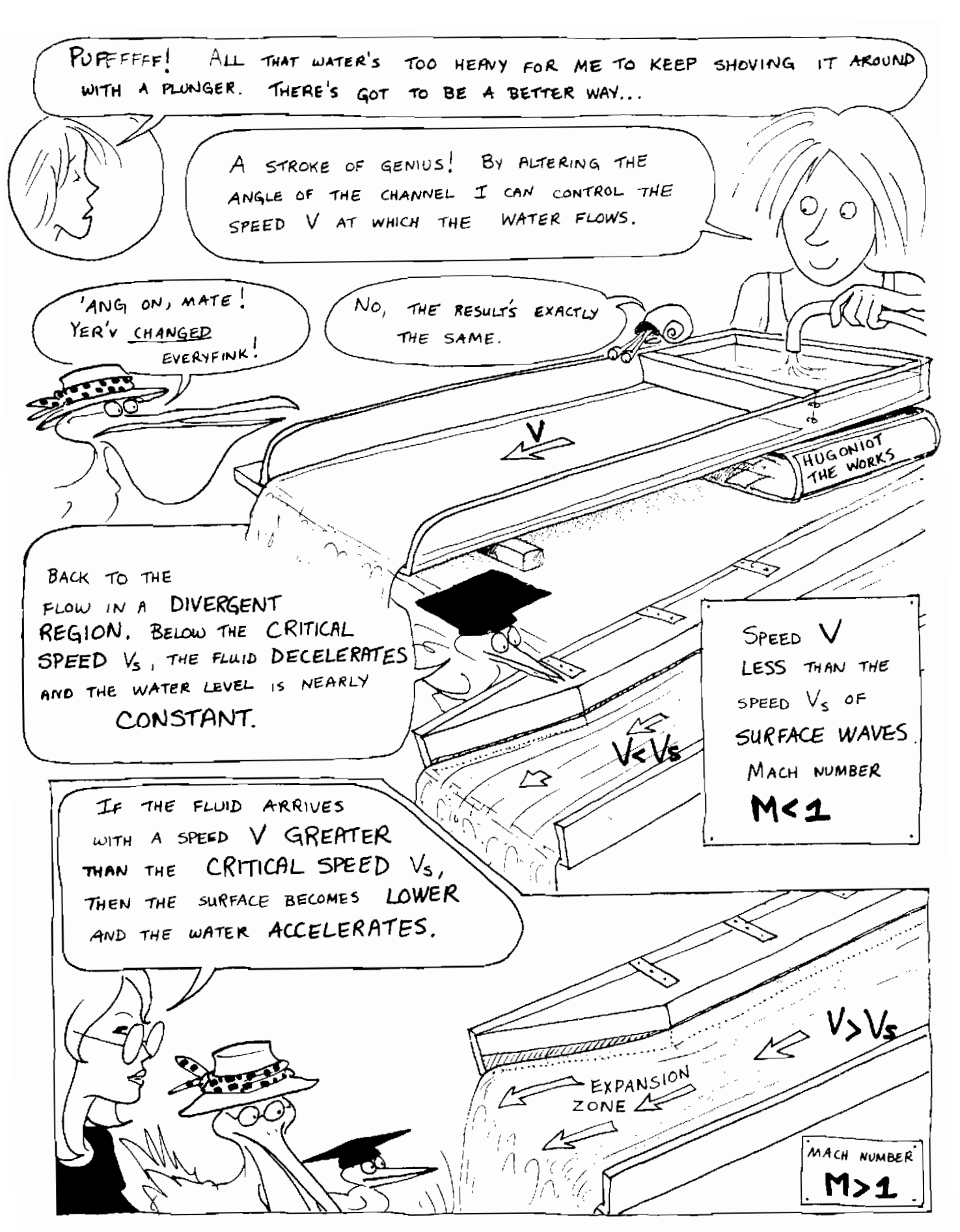
IF YOU PULL GENTLY AND THE SPEED V OF THE FLUID ALWAYS STAYS LESS THAN THE SPEED V_S OF SURFACE WAVES, THEN THE WATER DECELERATES IN THIS DIVERGENT REGION, AND THE HEIGHT OF THE WATER REMAINS VIRTUALLY CONSTANT.



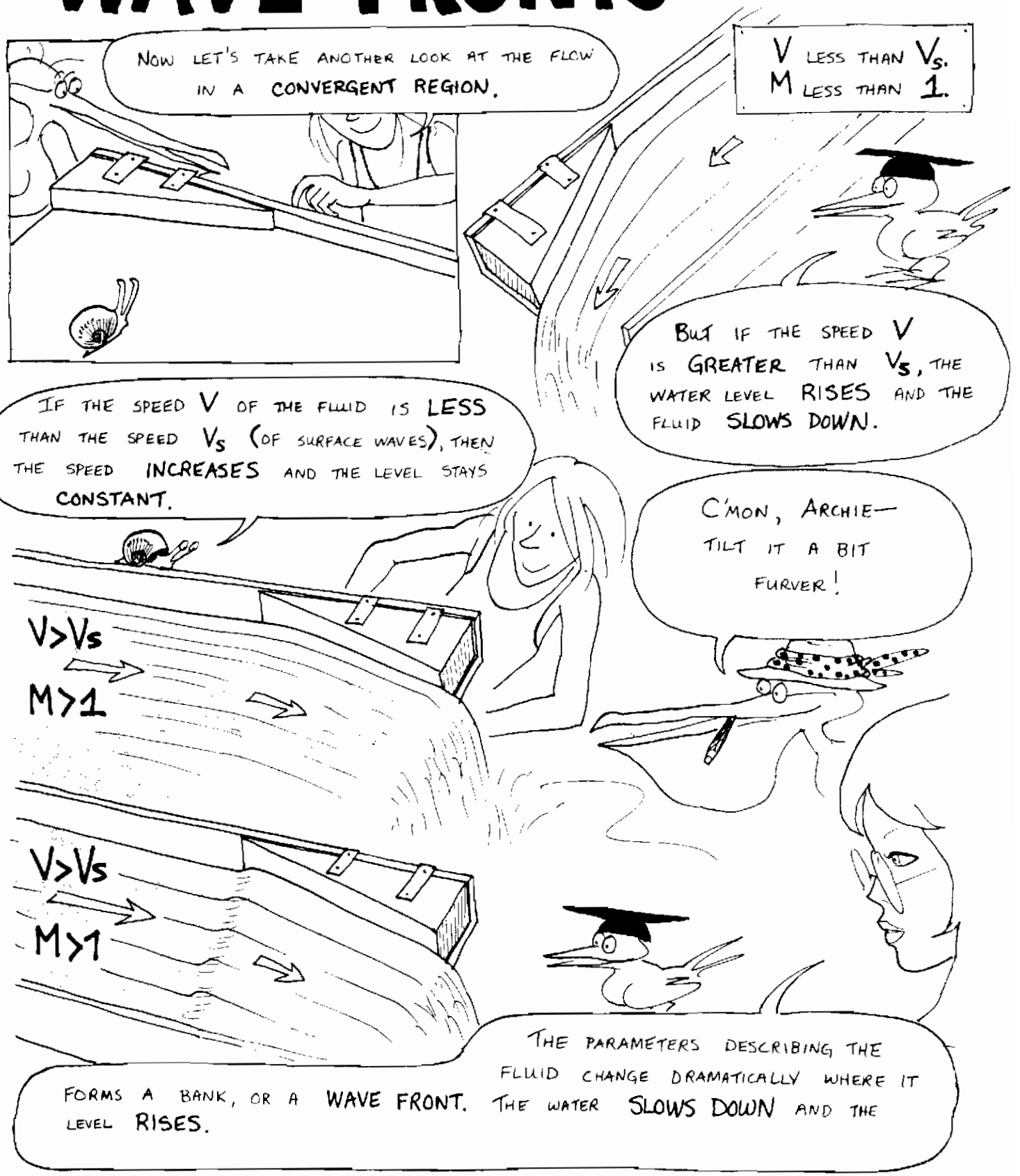
THESE TWO RADICALLY DIFFERENT KINDS OF BEHAVIOR ARE SUMMED UP IN THE THEOREM OF THE FRENCH PHYSICIST HUGONIOT:

Hugoniot	SPEED V LESS THAN THE SPEED V_S OF SURFACE WAVES (MACH NUMBER $M < 1$)	SPEED V GREATER THAN THE SPEED V_S OF SURFACE WAVES (MACH NUMBER $M > 1$)
IN A CONVERGENT REGION THE FLUID:	ACCELERATES	DECELERATES
THE LEVEL:	STAYS CONSTANT	RISES
IN A DIVERGENT REGION THE FLUID:	DECELERATES	ACCELERATES
THE LEVEL:	STAYS CONSTANT	DROPS

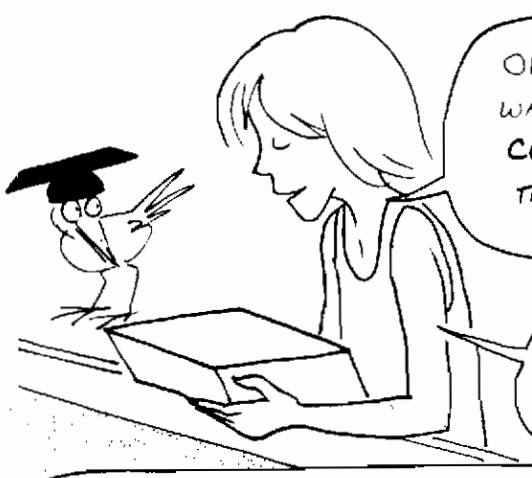



PUFFFFFF! ALL THAT WATER'S TOO HEAVY FOR ME TO KEEP SHOVING IT AROUND WITH A PLUNGER. THERE'S GOT TO BE A BETTER WAY...
A STROKE OF GENIUS! BY ALTERING THE ANGLE OF THE CHANNEL I CAN CONTROL THE SPEED V AT WHICH THE WATER FLOWS.
'ANG ON, MATE! YER'V CHANGED EVERYFINK!
NO, THE RESULT'S EXACTLY THE SAME.
V
HUGONIOT THE WORKS
BACK TO THE FLOW IN A DIVERGENT REGION. BELOW THE CRITICAL SPEED V_s, THE FLUID DECELERATES AND THE WATER LEVEL IS NEARLY CONSTANT.
$V<V_s$
SPEED V LESS THAN THE SPEED V_s OF SURFACE WAVES. MACH NUMBER $M<1$
IF THE FLUID ARRIVES WITH A SPEED V GREATER THAN THE CRITICAL SPEED V_s, THEN THE SURFACE BECOMES LOWER AND THE WATER ACCELERATES.
$V>V_s$
EXPANSION ZONE
MACH NUMBER $M>1$

WAVE FRONTS


NOW LET'S TAKE ANOTHER LOOK AT THE FLOW IN A CONVERGENT REGION.
V LESS THAN V_s.
M LESS THAN 1.
BUT IF THE SPEED V IS GREATER THAN V_s, THE WATER LEVEL RISES AND THE FLUID SLOWS DOWN.
IF THE SPEED V OF THE FLUID IS LESS THAN THE SPEED V_s (OF SURFACE WAVES), THEN THE SPEED INCREASES AND THE LEVEL STAYS CONSTANT.
C'MON, ARCHIE— TILT IT A BIT FURVER!
V>Vs
M>1
V>Vs
M>1
THE PARAMETERS DESCRIBING THE FLUID CHANGE DRAMATICALLY WHERE IT FORMS A BANK, OR A WAVE FRONT. THE WATER SLOWS DOWN AND THE LEVEL RISES.

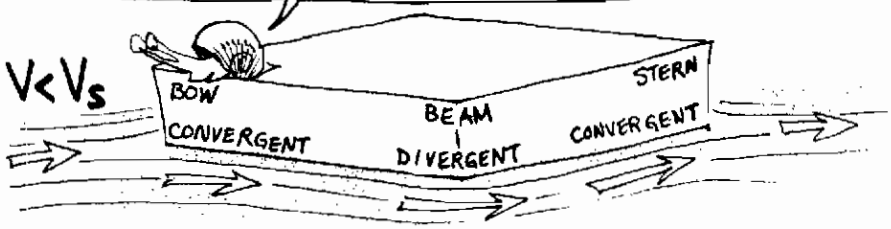
FLOW ROUND A CONTOUR

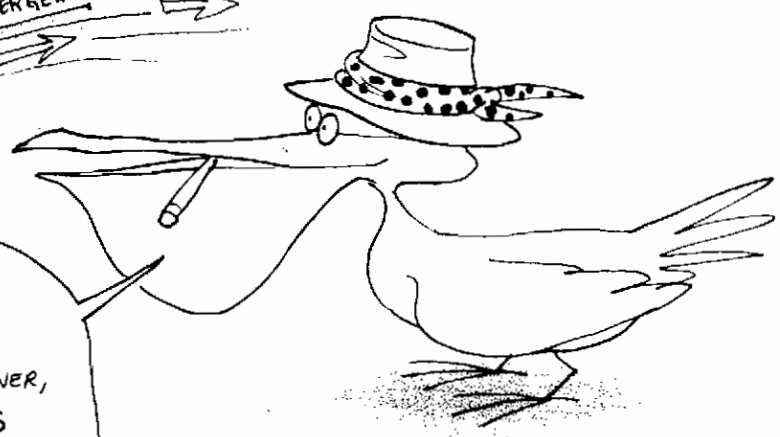


OK, NOW THAT WE'VE SORTED ALL THAT OUT, I WANT TO STUDY THE FLOW OF A FLUID AROUND A **CONTOUR**. I'LL START IN A REGIME WHERE THE SPEED V OF THE FLUID IS **LESS** THAN V_s.

I'LL FAKE UP A BOAT SHAPE WITH **THREE** SUCCESSIVE CORNERS.

THE FLUID ACCELERATES AT THE BOW, WHICH FORMS A **CONVERGENT REGION.**



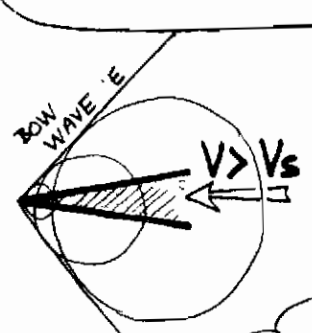


HMMM... YUR, THAT'S WOT IT BOILS DAHN TER. THE SPEED'S **FASTEST** ARAHND THE SECOND CORNER, THE **BEAM**. SO THE FLUID **SLOWS DAHN** UNTIL IT REACHES THE **STERN**, STAYIN' AT A **CONSTANT** BLINKIN' **LEVEL** UNTIL IT GETS BACK TER THE SAME SPEED WOT IT 'AD AT THE **BOW**.


THE SURFACE WAVES, TRAVELING AT A SPEED V_s, CAN MOVE UPSTREAM AND TRANSMIT ENERGY TO THE FLUID. SO THE FLUID "KNOWS" THAT AN OBJECT IS COMING AND HAS TIME TO GET ITSELF READY TO MEET IT. IT BEGINS TO MOVE APART BEFORE THE OBJECT ARRIVES.
V<Vs
Vs
AHOY UPSTREAM! HERE WE COME!
NOW I'M GOING TO TILT THE CHANNEL A BIT MORE SO THAT THE SPEED V OF THE FLUID BECOMES GREATER THAN THE SPEED V_s OF SURFACE WAVES.
BY HUGONIOT'S THEOREM, WE KNOW THAT THE FLUID SLOWS DOWN AT THE BOW, SPEEDS UP AT THE BEAM, AND SLOWS DOWN AGAIN AT THE STERN.
V>Vs
BOW
BEAM
STERN
LEVEL WITH THE BOW, THE WATER IS SUDDENLY SLOWED DOWN AND RISES HIGHER THAN THE ORIGINAL WATERLINE. ON PASSING THE SECOND CORNER, THE WATER IS SPEEDED UP AGAIN, EVEN SUPERACCELERATED, THAT IS, INCREASED TO A SPEED GREATER THAN THAT OF "FREE" FLOW. AT THE SAME TIME THE LEVEL DROPS BELOW THE WATERLINE. LEVEL WITH THE STERN, THE SPEED AND LEVEL ARE SUDDENLY READJUSTED TO THEIR ORIGINAL VALUES UPSTREAM.

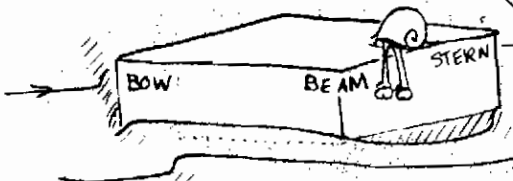
THE BOW WAVE

IN THIS REGIME, WHERE THE SPEED V IS GREATER THAN THE SPEED V_s OF SURFACE WAVES, WE FIND **WAVEFRONTS**. THE BOW, FOR EXAMPLE, EMITS SURFACE WAVES THAT TRAVEL TOO SLOWLY TO MOVE UPSTREAM AND THEREFORE PILE UP AGAINST EACH OTHER TO FORM A MOUND OF LIQUID, THE **BOW WAVE**.

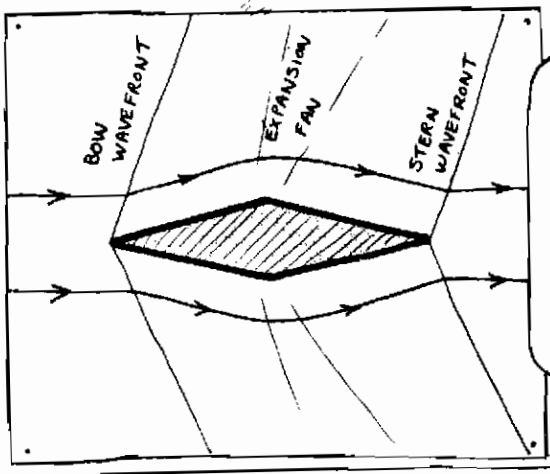


SO THEN YER GETS A BEAM-WAVE AT THE MIDDLE CORNER?

NO, YOU DON'T GET "EXPANSION FRONTS." LOOKS AS IF THEY ONLY HAPPEN GENTLY.



THE ONE TIME I MANAGES TER FINK UP SOMEFINK ORIGINAL, AN' IT'S A FLOP!



TIRESIAS IS RIGHT, LENNY. THE CHANGES IN SPEED AND LEVEL HAPPEN SUDDENLY AT THE BOW AND STERN, BY MEANS OF **WAVEFRONTS**. IN CONTRAST, AT THE BEAM, THE SPEED AND LEVEL CHANGE CONTINUOUSLY, ACROSS AN **EXPANSION FAN**.

OBSERVATION, LENNY. OBSERVATION!

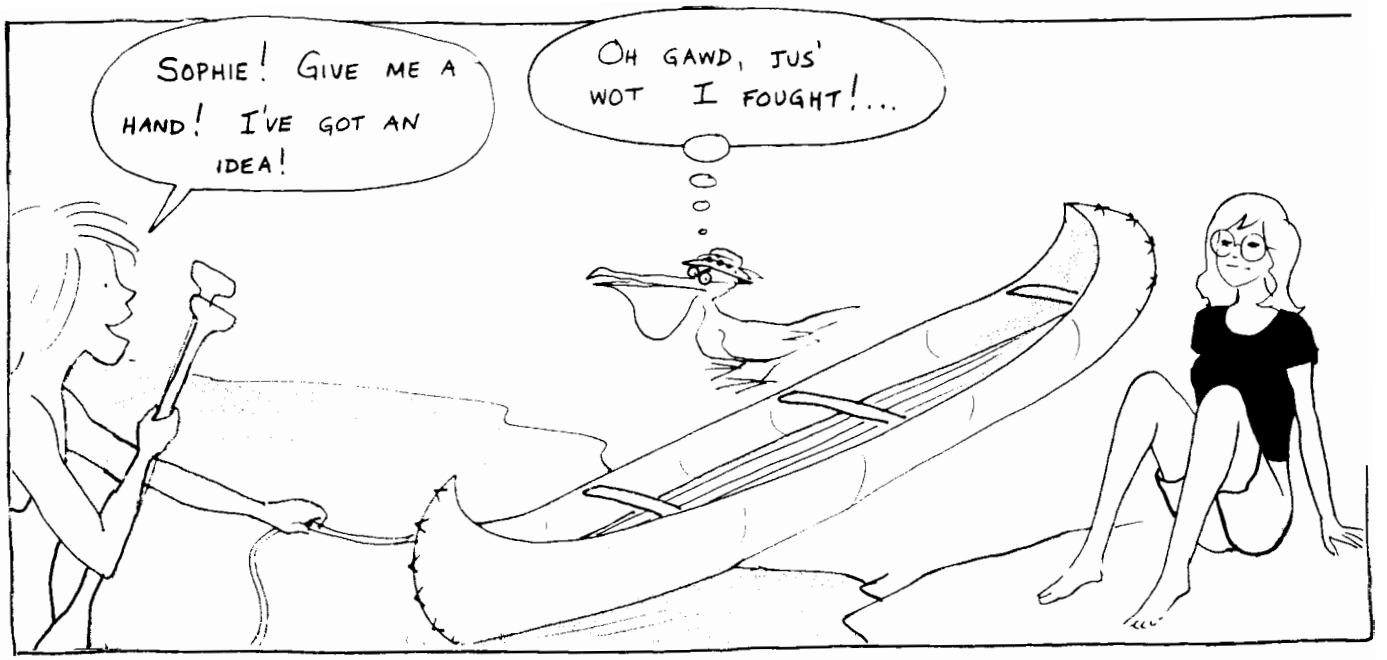

TIRESIAS IS RIGHT.
FLAP FLAP
'S NOT EASY TER SEE WOT'S 'APPENIN' UNDER YER WINGS....
AH, IT'S H'OBVIOUS ENUFF NOW!
LOOK OUT! MIND THE BANK!...
ANOTHER SACRIFICE IN THE NAME OF SCIENCE.
IN A REAL BOAT HULL, THE BEAM IS FORMED BY A SUCCESSION OF VERY MANY TINY CORNERS.
UPSTREAM
DOWNSTREAM
AND THE STERN WAVE ASSURES A SMOOTH JOIN WITH THE FLUID DOWNSTREAM— WHICH IS WHY BOATS DON'T LEAVE FURROWS BEHIND THEM.
IN THE SAME WAY, THE REMAINING DIFFERENCE IN SPEED, DUE TO WATER BEING CARRIED ALONG WITH THE BOAT BY FRICTION, IS CANCELLED OUT BY THE TURBULENCE OF THE BOAT'S WAKE.
HEY! I'VE DISCOVERED THE FUNDAMENTAL PRINCIPLE OF FLUID MECHANICS!!
YET AGAIN, TIRESIAS OLD BEAN, YER ASTOUNDS ME. WHAT?
PLEASE LEAVE THE FLUID IN THE STATE IN WHICH YOU WOULD WISH TO FIND IT

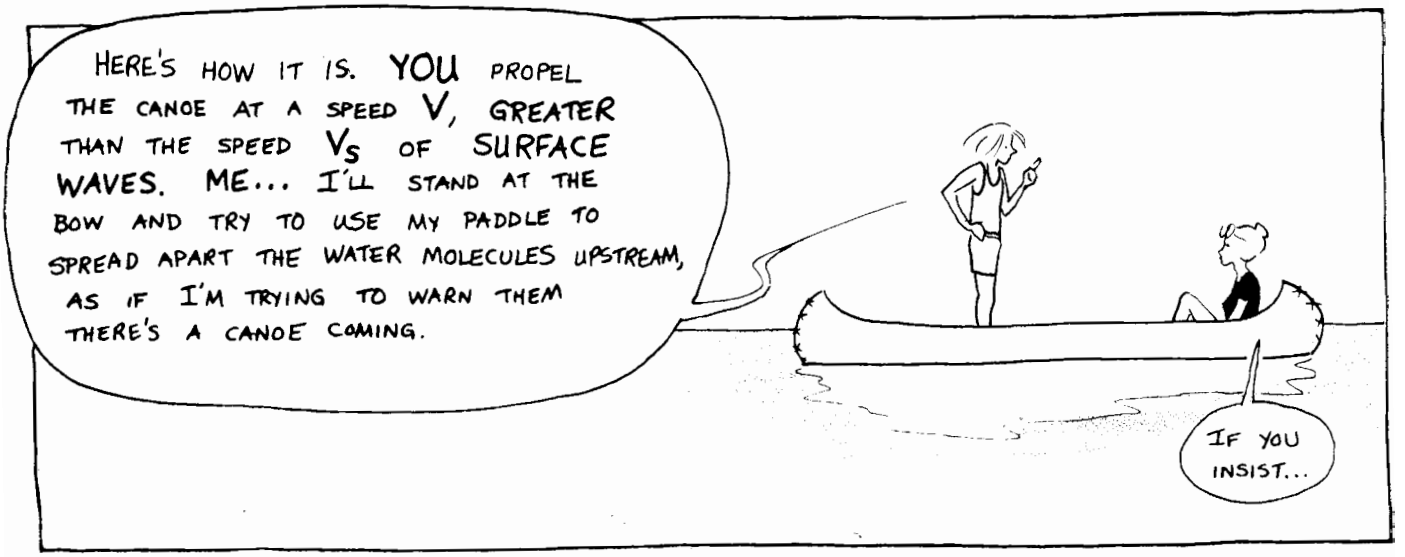
MEASUREMENT OF SPEED

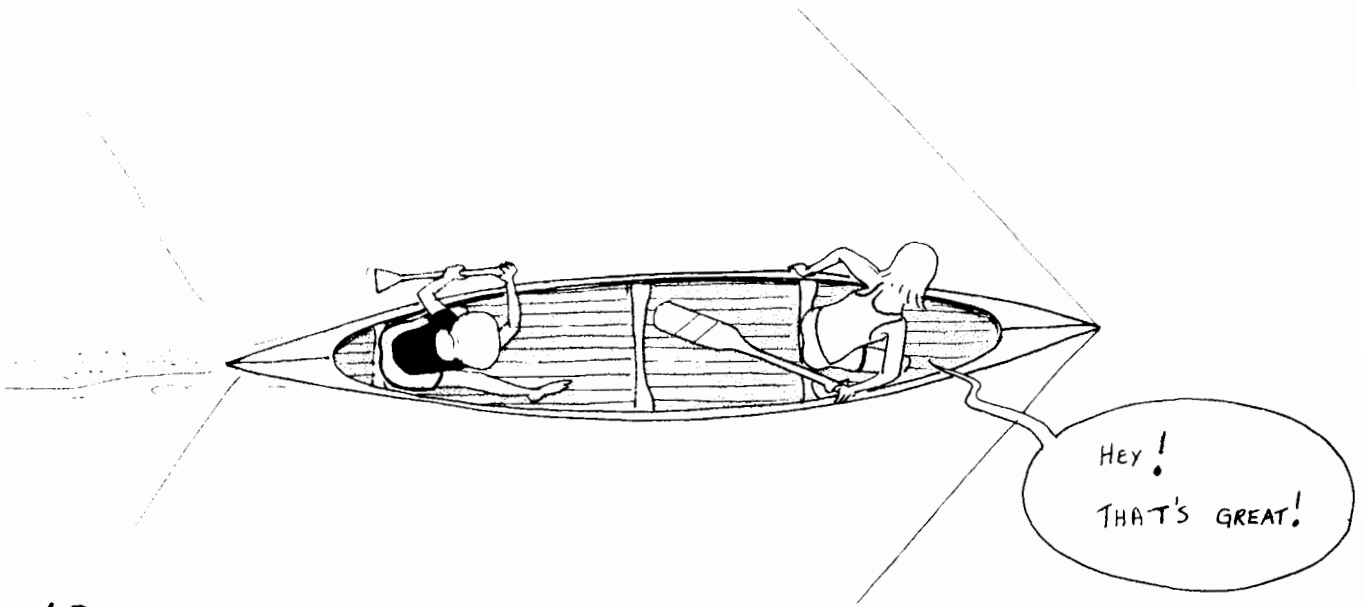
(*) SEE APPENDIX A (PAGE 71).


THAT'S ONLY TO BE EXPECTED. IN THIS REGION, NEAR A BLUNT BOW, THE SPEED V FALLS BELOW THE CRITICAL SPEED Vs.
IT'S ALMOST AS IF THE OBJECT USES THE BOW WAVE TO BUILD ITSELF A REGION WHERE V IS LESS THAN Vs TO MAKE IT EASIER TO NAVIGATE.
BUT THEN, 'OW CAN THE WATER GEDDAHT O' THE WAY, WHEN ITS SPEED'S SO BLINKIN' LOW?
ELEMENTARY, MY DEAR PELICAN: WHERE THE FLUID SLOWS DOWN, THE LEVEL RISES, AND VICE VERSA.
IT'S ALL BEGINNING TO MAKE SOME KIND OF SENSE.
COME ALONG, YE SEEKERS AFTER KNOWLEDGE! DINNER TIME!


YOU KNOW, IT WOULDN'T BE A BAD THING IF YOU COULD GET RID OF THOSE WAVES.
THEY WASTE ENERGY, THAT'S FOR SURE!
OH 'ECK! SUMFINK'S BREWIN'!
YES, THERE'S ENERGY THERE ALL RIGHT. THE PROOF IS THAT THE GUY IN THE SPEEDBOAT DEMOLISHED OUR LANDING-STAGE.
IF YOU COULD GET ADVANCE WARNING OF THE FLUID AHEAD, THE WAVE WOULDN'T FORM....
SO... TO MOVE FASTER THAN SURFACE WAVES, YOU HAVE TO BE ABLE TO CONTINUE TO ACT ON THE FLUID UPSTREAM.
HEY!
DISHES, ARCHIBALD....
THERE'S GOT TO BE A WAY.
AHA!
SNAP!

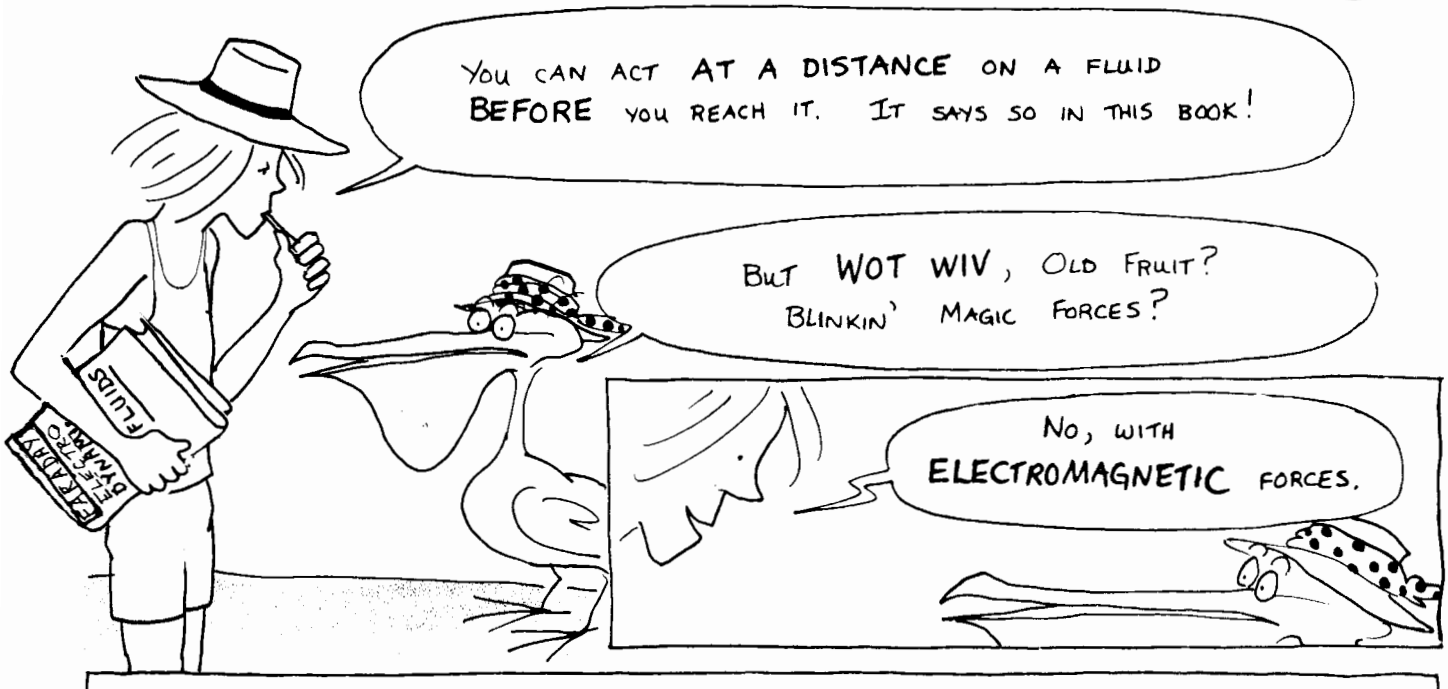

SOPHIE! GIVE ME A HAND! I'VE GOT AN IDEA!
OH GAWD, JUS' WOT I FOUGHT!...


HERE'S HOW IT IS. YOU PROPEL THE CANOE AT A SPEED V, GREATER THAN THE SPEED V_S OF SURFACE WAVES. ME... I'LL STAND AT THE BOW AND TRY TO USE MY PADDLE TO SPREAD APART THE WATER MOLECULES UPSTREAM, AS IF I'M TRYING TO WARN THEM THERE'S A CANOE COMING.
IF YOU INSIST...


HEY! THAT'S GREAT!


NOW WE'LL SEE!
WE'LL SEE, ALL RIGHT.
UH-HUH!
I GUESS THAT'S NOT IT.
WHAT WERE YOU DOING?
NOTHING. ARCHIE WAS JUST WARNING THE MOLECULES.
IT CAN'T POSSIBLY WORK, YOU KNOW! IF YOU WANT TO "WARN" THE MOLECULES, AS YOU SAID, THEN YOU'VE GOT TO PUT SOME OTHER MATERIAL OBJECTS INTO THE WATER UPSTREAM... AND THOSE WILL JUST CREATE THEIR OWN WAVES. IT'S A VICIOUS CIRCLE.
WAIT, WAIT...
SOPHIE SAYS THAT ALL YER DOIN' IS POSTPONIN' THE PROBLEM.
FARADAY
SHE SAYS IT'S IMPOSSIBLE TO SAIL A BOAT WITHOUT MAKING A BOW WAVE.

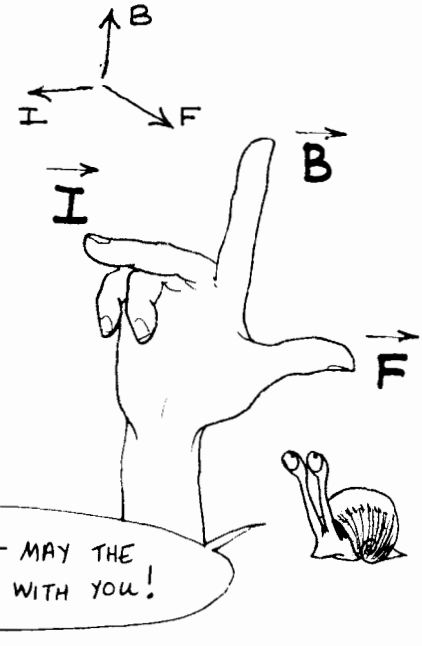
iN WHiCH ARCHiE DiSCOVERS MAGNETOHYDRODYNAMiCS



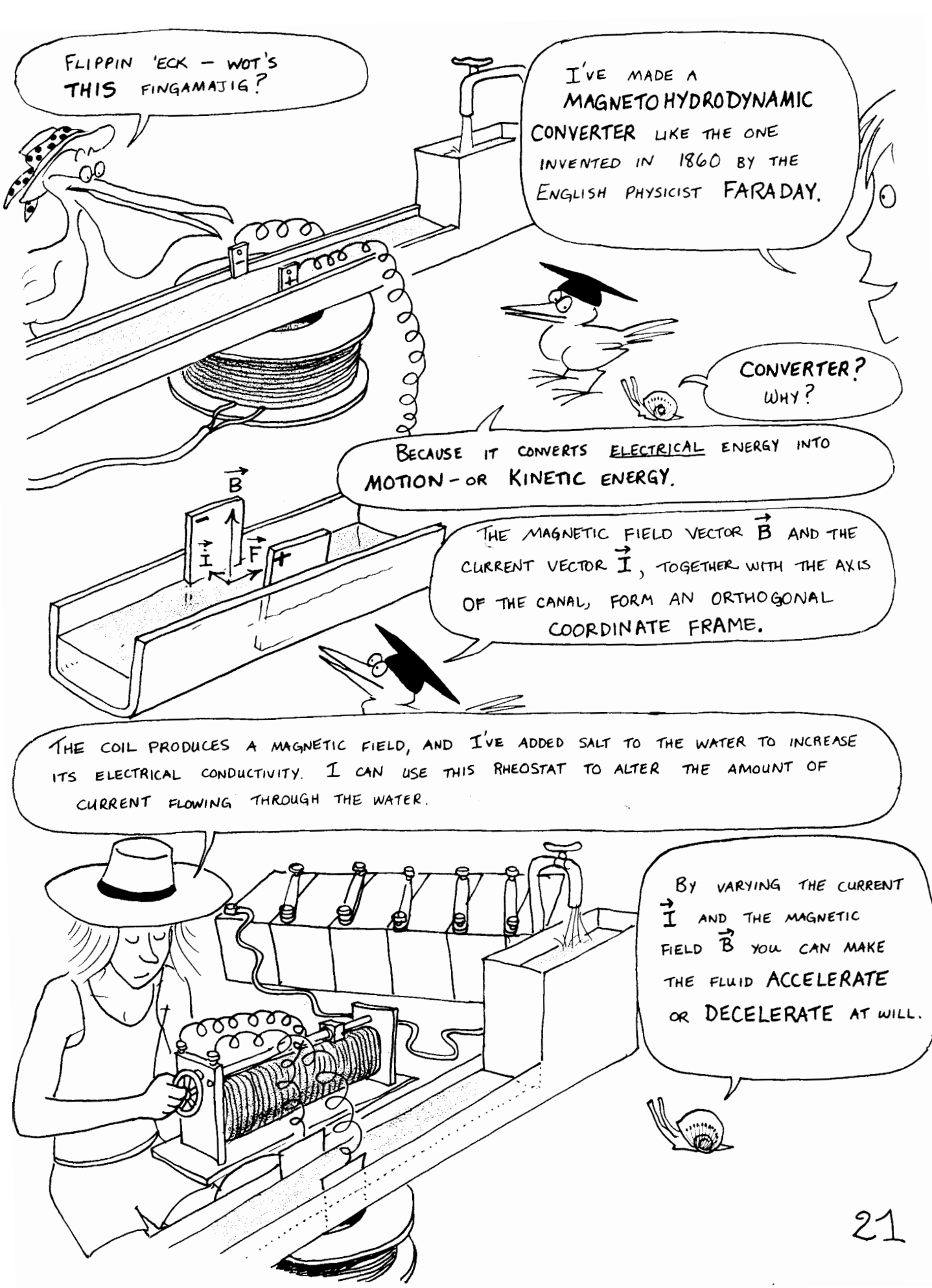
If, in a fluid, you create a **MAGNETIC FIELD** $\vec{B}$ and an **ELECTRIC CURRENT** $\vec{I}$, which is **PERPENDICULAR**, then the fluid experiences a **LAPLACE FORCE** of intensity **IB**, whose direction is given by the

RIGHT-HAND RULE:

Hold the thumb, index finger, and middle finger of the right hand as shown. Suppose that the **CURRENT** flows in the direction of the middle finger and the **MAGNETIC FIELD**, in the direction of the **INDEX** finger. Then the **FORCE** acts in the direction of the **THUMB**.



The Boss


FLIPPIN 'ECK – WOT'S THIS FINGAMAJIG?
I'VE MADE A MAGNETOHYDRODYNAMIC CONVERTER LIKE THE ONE INVENTED IN 1860 BY THE ENGLISH PHYSICIST FARADAY.
CONVERTER? WHY?
BECAUSE IT CONVERTS ELECTRICAL ENERGY INTO MOTION – OR KINETIC ENERGY.
B
I
F
THE MAGNETIC FIELD VECTOR B AND THE CURRENT VECTOR I, TOGETHER WITH THE AXIS OF THE CANAL, FORM AN ORTHOGONAL COORDINATE FRAME.
THE COIL PRODUCES A MAGNETIC FIELD, AND I'VE ADDED SALT TO THE WATER TO INCREASE ITS ELECTRICAL CONDUCTIVITY. I CAN USE THIS RHEOSTAT TO ALTER THE AMOUNT OF CURRENT FLOWING THROUGH THE WATER.
BY VARYING THE CURRENT I AND THE MAGNETIC FIELD B YOU CAN MAKE THE FLUID ACCELERATE OR DECELERATE AT WILL.

INTERACTION CRITERION

... BUT LET'S NOT WORRY ABOUT THAT NOW. LOGICALLY, IF THE ENERGY TRANSMITTED BY THE **LAPLACE FORCES** IS **GREATER** THAN THE KINETIC ENERGY OF THE FLUID, WE SHOULD BE ABLE TO **CONTROL** THE FLOW COMPLETELY.

WHAAT!?! MAX, YER GORN BONKERS!!!

WELL, I MUST SAY, WE REALLY ARE ALL HAVING FUN AND GAMES TODAY, AREN'T WE?

'SAY NO MORE, SUNSHINE, SAY NO MORE. YER KNOWS WOT BLINKIN' 'IGGINS IS LIKE. GIVE 'IM AN INCH AN' 'E'LL 'ANG 'IMSELF!

IF ONLY SOPHIE WERE 'ERE! BUT SHE'S SUNNIN' 'ERSELF ON THE BEACH.

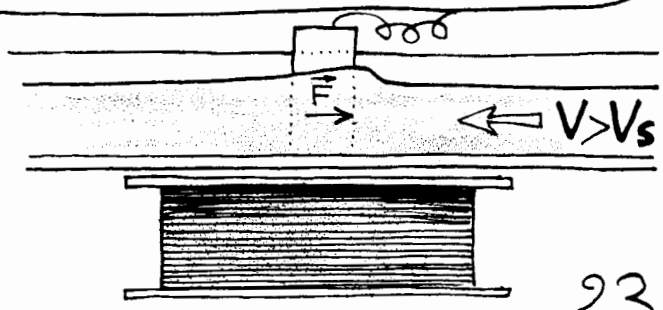
BLEEDIN' NONSENSE ANYWAY, 'IS RUDDY **MOSQUITO - 'YDRO - DYNAMO** - WOTSIT....

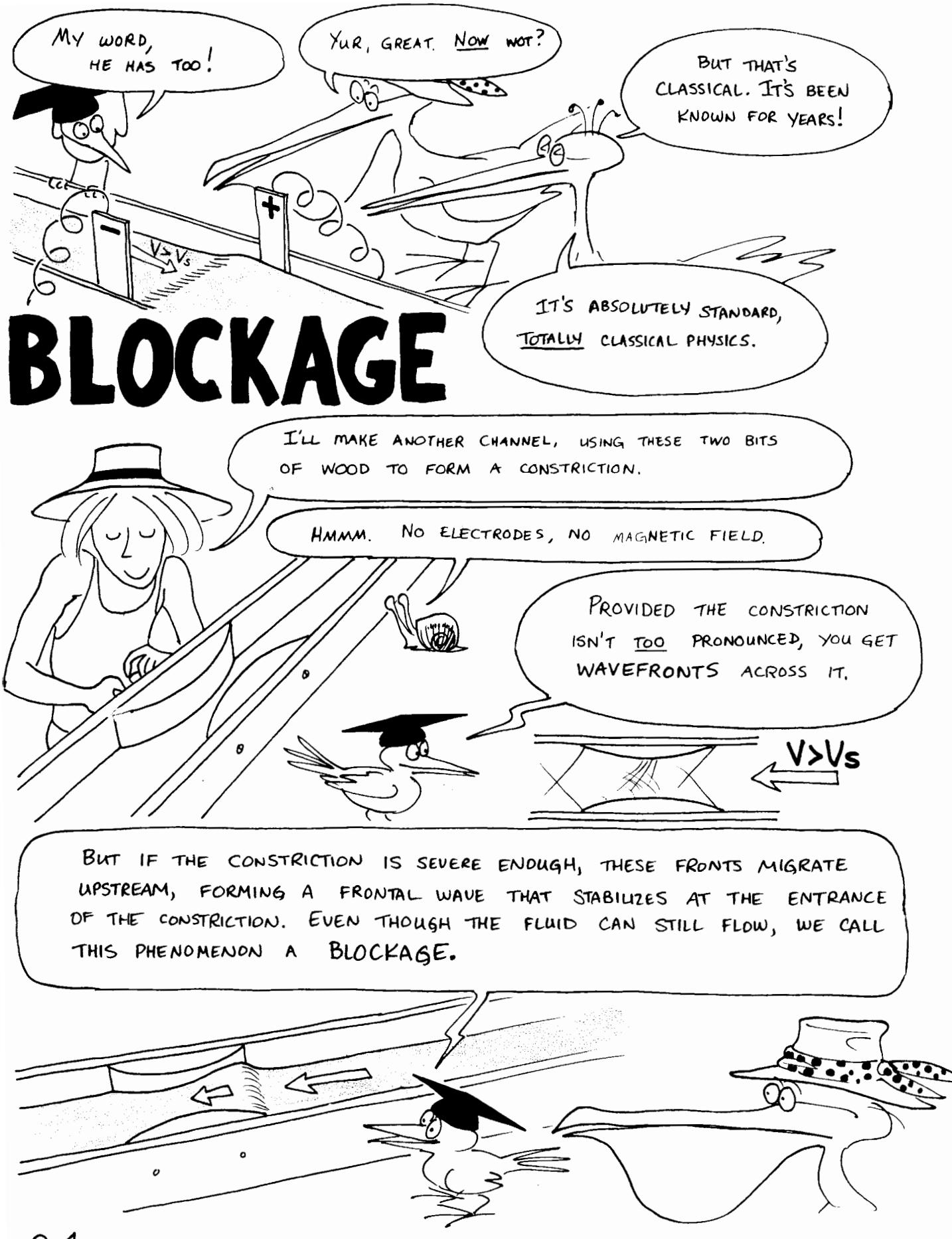
BAH, YOU'RE AFRAID OF YOUR OWN SHADOW! IT'S ALL LOW-VOLTAGE STUFF ANYWAY. THE SKY WON'T FALL IN WITH 40 VOLTS AND 10,000 GAUSS, DAMMIT!

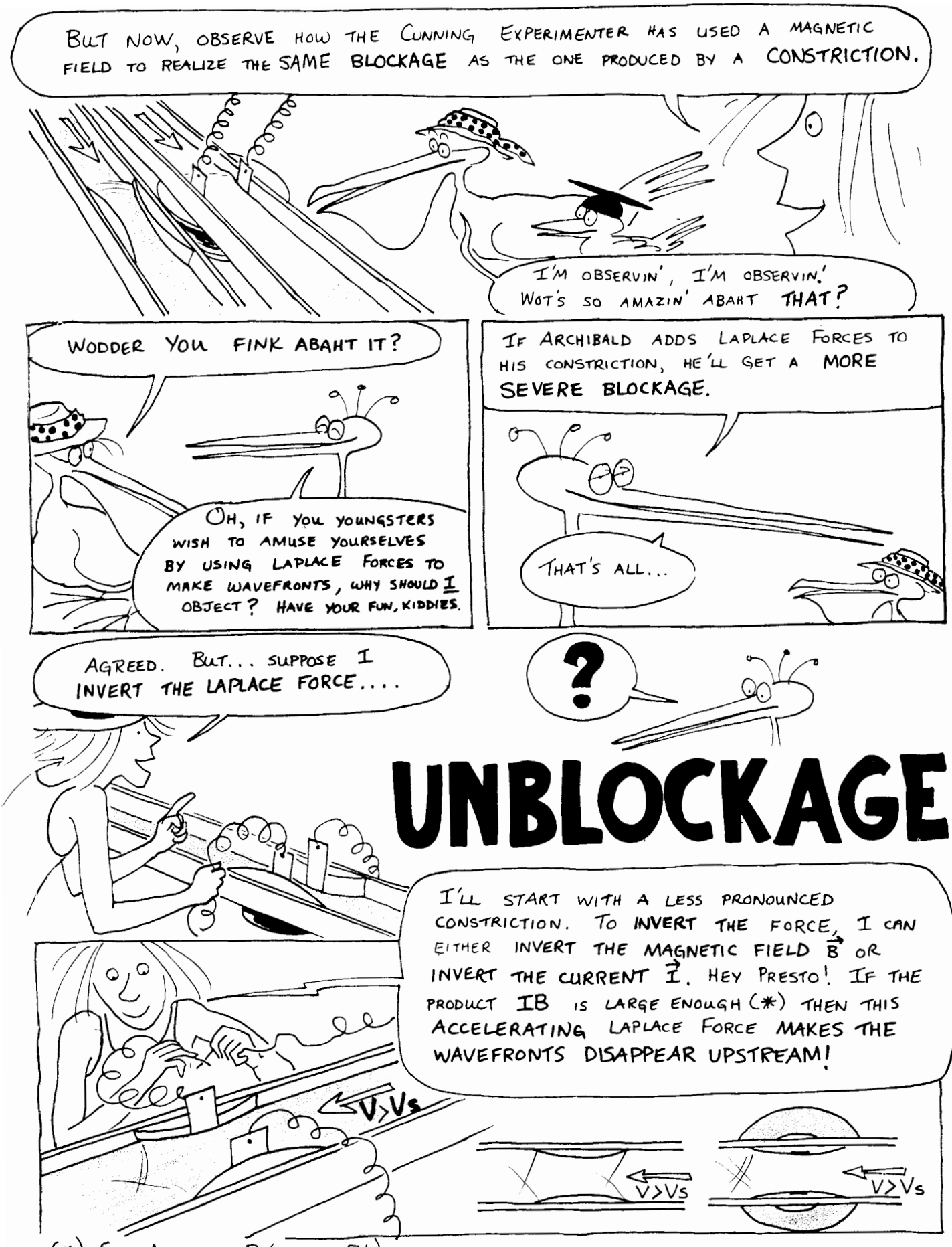
COME ON NOW... MAGNETOHYDRODYNAMICS, ABBREVIATED **MHD**... YOU'LL EVEN FIND IT IN THE DICTIONARY!

WOW! LOOK!

BY USING THE SYSTEM AS A **DECELERATOR** AND USING JUST THE RIGHT AMOUNT OF ENERGY, I'VE MANAGED TO CREATE A **STATIONARY WAVE FRONT** WITH NO OBSTACLE OTHER THAN THE **LAPLACE FORCES** IB.

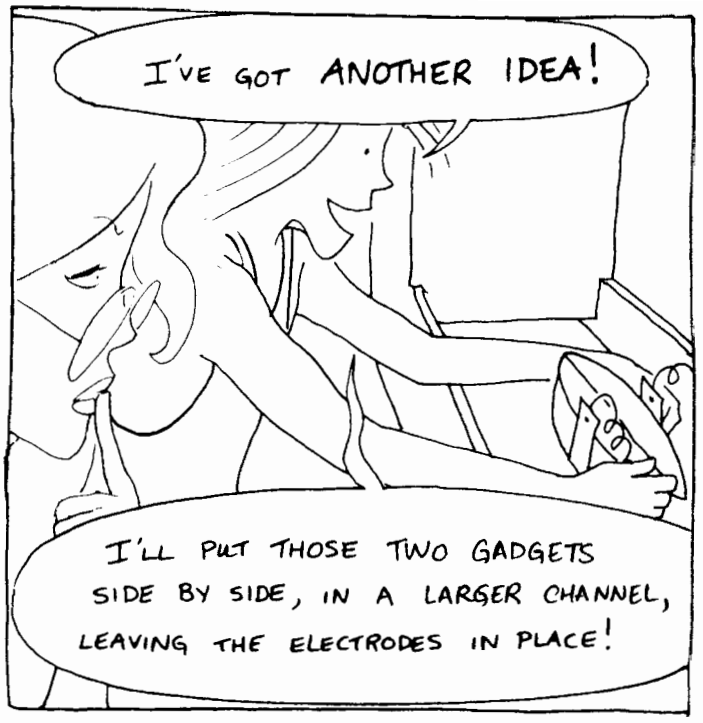



MY WORD, HE HAS TOO!
YUR, GREAT. NOW WOT?
BUT THAT'S CLASSICAL. IT'S BEEN KNOWN FOR YEARS!
V>Vs
IT'S ABSOLUTELY STANDARD, TOTALLY CLASSICAL PHYSICS.
BLOCKAGE
I'LL MAKE ANOTHER CHANNEL, USING THESE TWO BITS OF WOOD TO FORM A CONSTRICTION.
HMMM. NO ELECTRODES, NO MAGNETIC FIELD.
PROVIDED THE CONSTRICTION ISN'T TOO PRONOUNCED, YOU GET WAVEFRONTS ACROSS IT.
V>Vs
BUT IF THE CONSTRICTION IS SEVERE ENOUGH, THESE FRONTS MIGRATE UPSTREAM, FORMING A FRONTAL WAVE THAT STABILIZES AT THE ENTRANCE OF THE CONSTRICTION. EVEN THOUGH THE FLUID CAN STILL FLOW, WE CALL THIS PHENOMENON A BLOCKAGE.

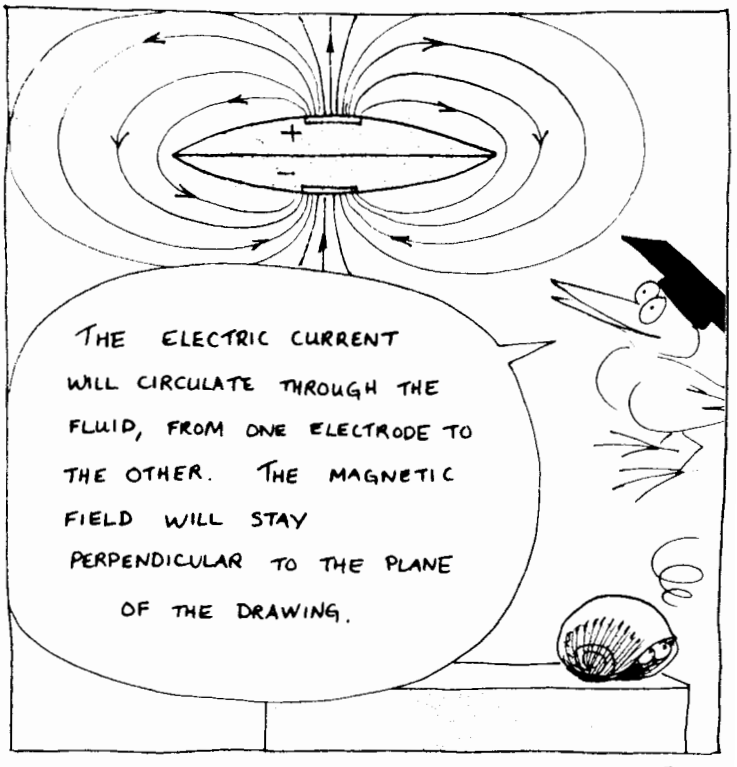


(*) SEE APPENDIX B (PAGE 71)

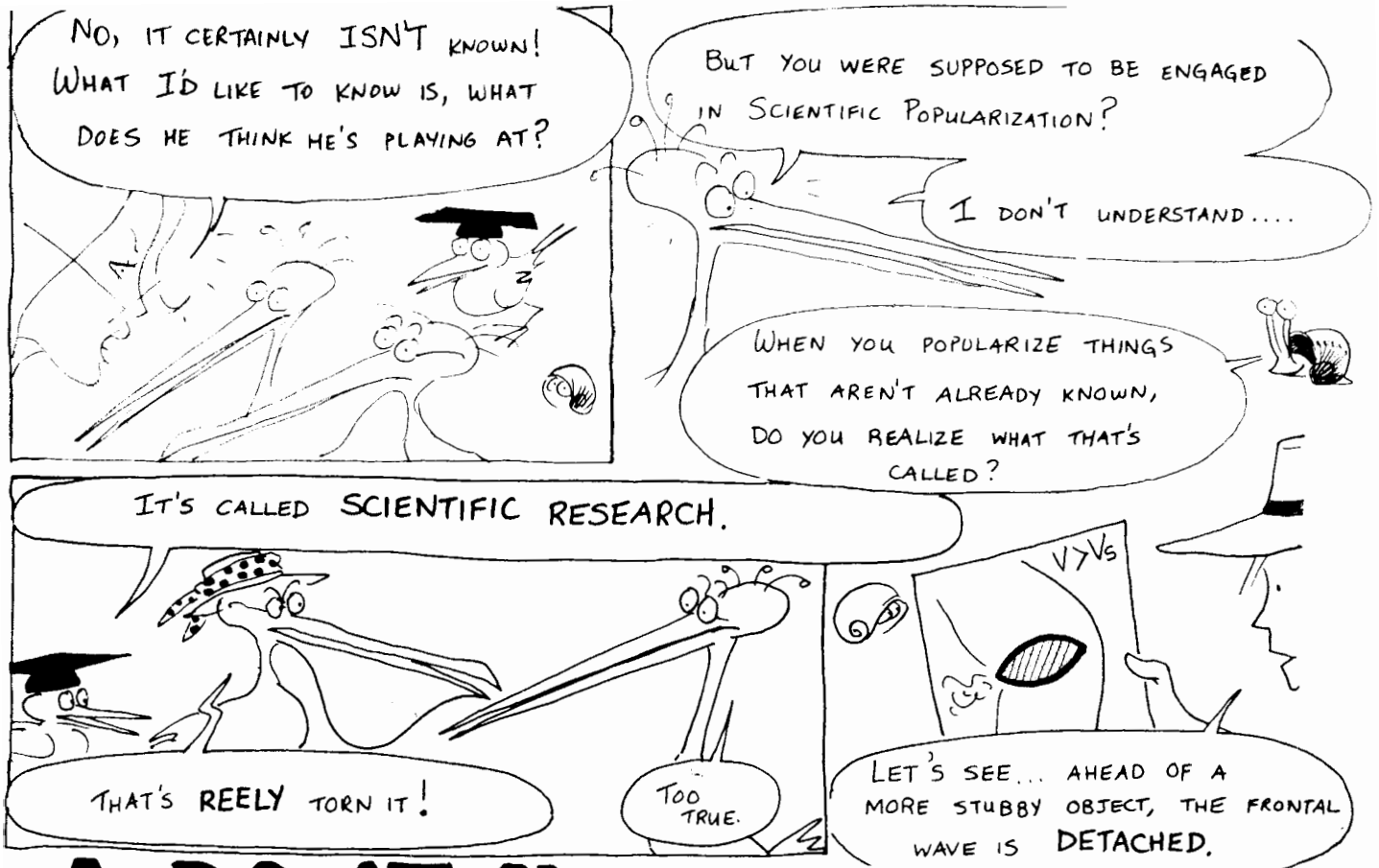

NOW LET'S SEE WHAT HAPPENS WITH A MORE PRONOUNCED CONSTRICTION...
HEY! THAT WORKS TOO!
TERRIFIC! I'M GOING TO FIND SOPHIE.
THE FRONTAL WAVE IS ANNIHILATED.
BLOCKAGE
WAVEFRONT
V>Vs
UNBLOCKAGE
DUE TO ACCELERATING LAPLACE FORCES.
DEPRESSION
V>Vs
BY INCREASING THE LAPLACE FORCES, ARCHIE CAN EVEN PRODUCE AN EFFECT OF SUCTION, ENOUGH TO LOWER THE LEVEL UPSTREAM AND CREATE A DEPRESSION.
SOPHIE! ARCHIE'S DISCOVERED SOMETHING IMPOSSIBLE!
TIRESIAS! YOU'RE ALL OUT OF BREATH? DID YOU RUN?



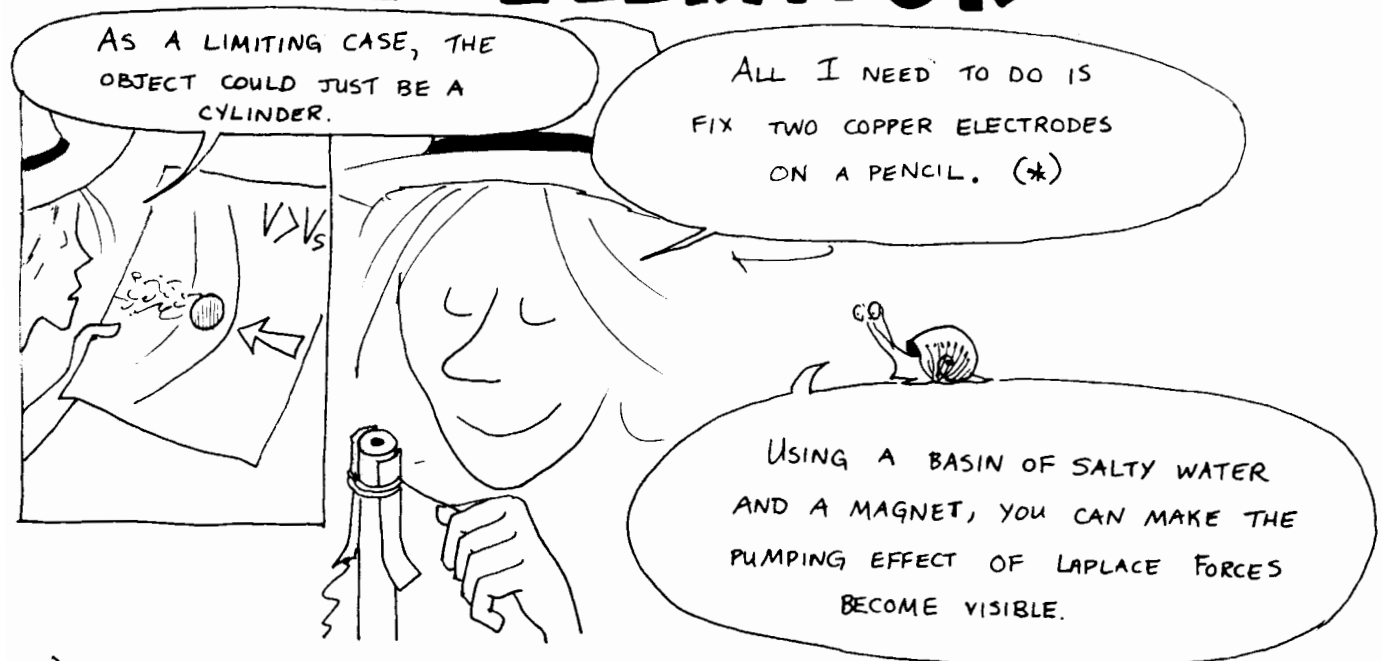
ANNIHILATION OF THE BOW WAVE



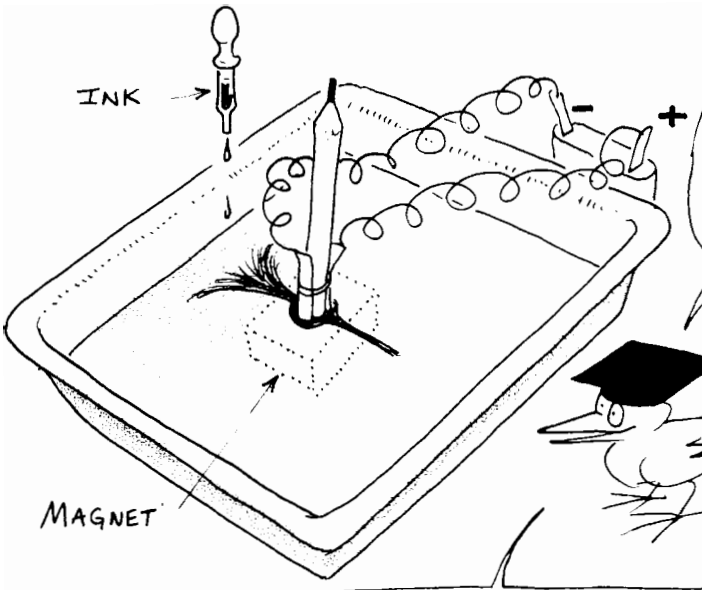

APPLYING THE RIGHT-HAND RULE, I CAN WORK OUT THE FIELD OF FORCES THAT WILL ACT ON THE FLUID.
SHIVER ME TIMBERS!
BY THE SHADES OF MAXWELL'S DEMON! ARCHIE HAS ANNIHILATED THE BOW WAVE!
WHAT?
V>V6
WHAT HAS HE MANAGED TO COME UP WITH?
NOTICE THAT ALTHOUGH HE'S SUPPRESSED THE BOW WAVE, THE STERN WAVE STILL PERSISTS....
BUT — SURELY THAT'S KNOWN... ISN'T IT?



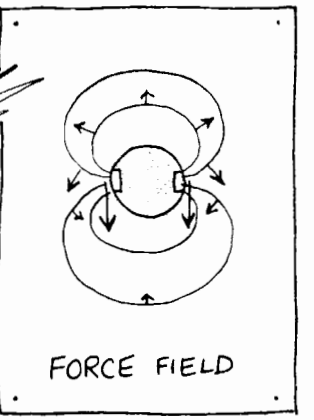
A DO-IT-YOURSELF MHD ACCELERATOR

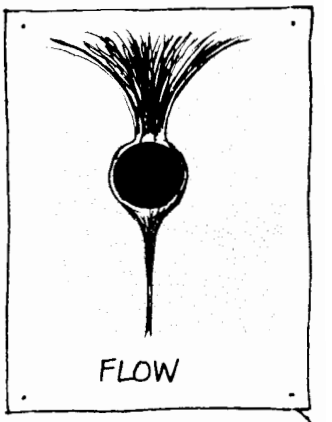


(*) AN ARRANGEMENT DEVISED IN 1976 BY MAURICE VITON.

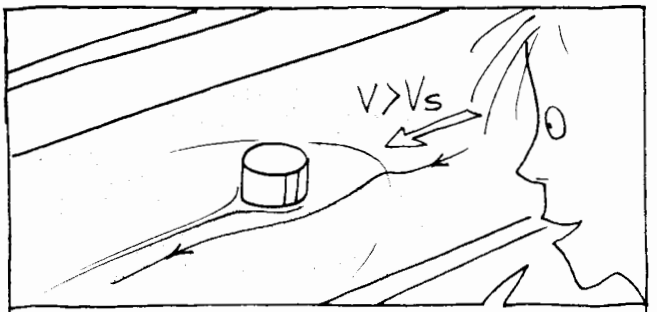


THE MAGNET, UNDERNEATH THE BASIN, PRODUCES A VERTICAL MAGNETIC FIELD $\vec{B}$. THE PUMPING EFFECT CAN BE SEEN BY USING A DROP OF INK.

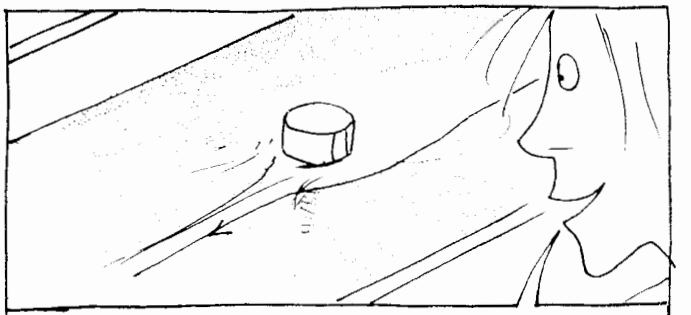




WITH A SMALL PERMANENT MAGNET AND A BATTERY, YOU CAN OBSERVE THE PUMPING EFFECT. BUT TO ACT ON THE FLUID STRONGLY ENOUGH TO CHANGE THE STRUCTURE OF THE WAVEFRONTS, THE LAPLACE FORCES MUST BE TEN TIMES LARGER.



I'LL PLACE THIS MODEL IN THE TEST CHANNEL AND INCREASE THE FORCE. TO BEGIN WITH THE WAVE IS NONTURBULENT, AND THE FRONTAL WAVE BENDS.



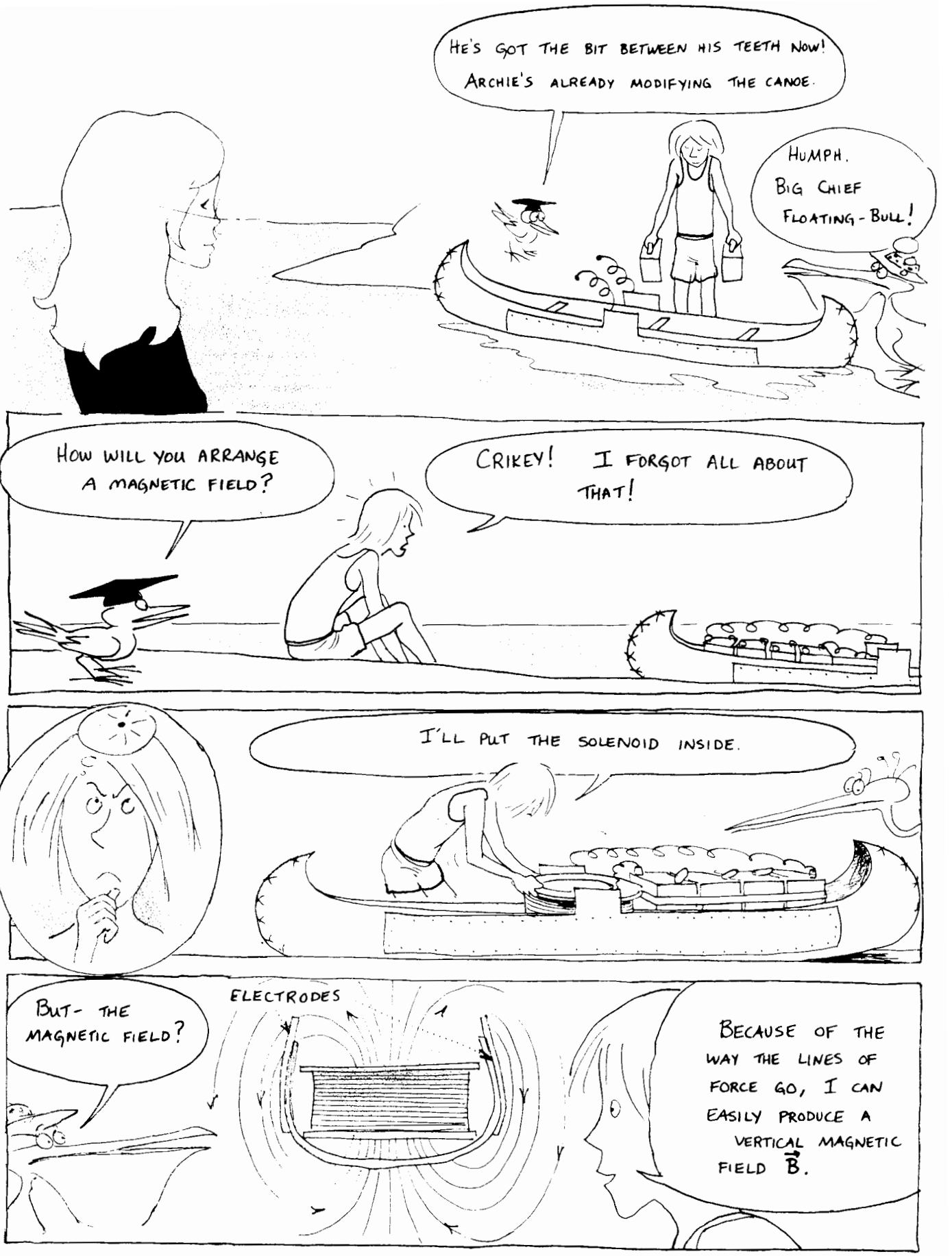
I'LL INCREASE THE FORCE FURTHER. THE FRONTAL WAVE DISAPPEARS, REPLACED BY A DEPRESSION IN THE LIQUID SURFACE.

GREAT! NOW FOR THE APPLICATIONS!

WAIT FOR ME, ARCHIE!

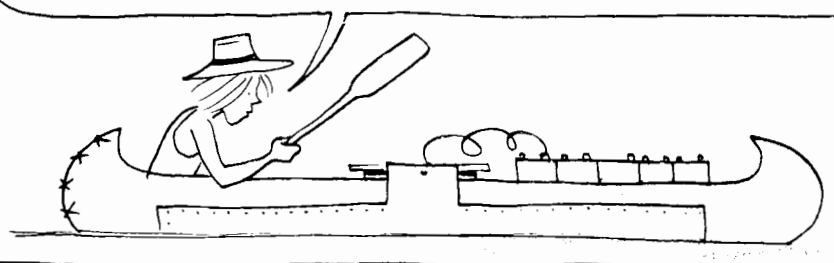
WODJER FINK, SOPHIE?

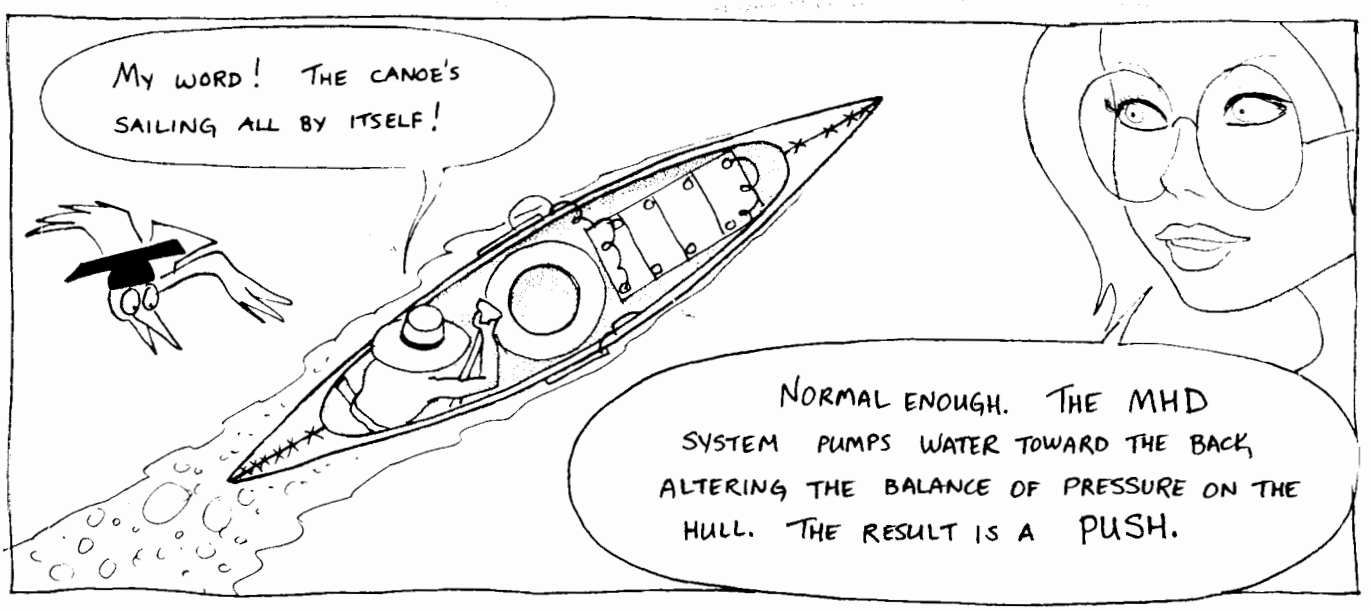
THE LAPLACE FORCES ACT AT A DISTANCE. I THINK ARCHIE HAS DISCOVERED HOW TO "WARN" THE FLUID UPSTREAM.

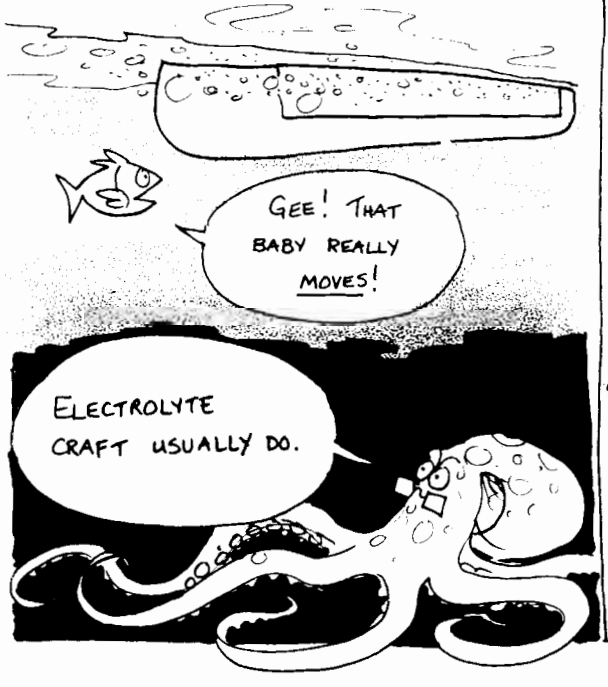

HE'S GOT THE BIT BETWEEN HIS TEETH NOW! ARCHIE'S ALREADY MODIFYING THE CANOE.
HUMPH. BIG CHIEF FLOATING-BULL!
HOW WILL YOU ARRANGE A MAGNETIC FIELD?
CRIKEY! I FORGOT ALL ABOUT THAT!
I'LL PUT THE SOLENOID INSIDE.
BUT- THE MAGNETIC FIELD?
ELECTRODES
BECAUSE OF THE WAY THE LINES OF FORCE GO, I CAN EASILY PRODUCE A VERTICAL MAGNETIC FIELD $\vec{B}$.

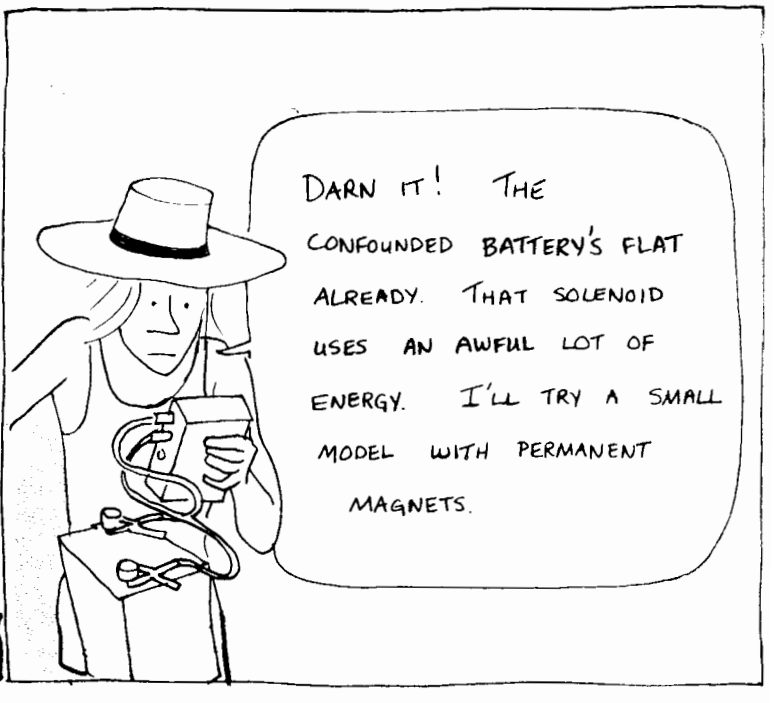
MHD PROPULSION

THE CUNNING EXPERIMENTER SETS OFF INTO THE UNKNOWN ABOARD HIS BOW WAVE ANNIHILATOR. ALL HE MUST DO NOW IS TO PADDLE THE CANOE AT A SPEED V GREATER THAN THE SPEED V_s OF SURFACE WAVES.



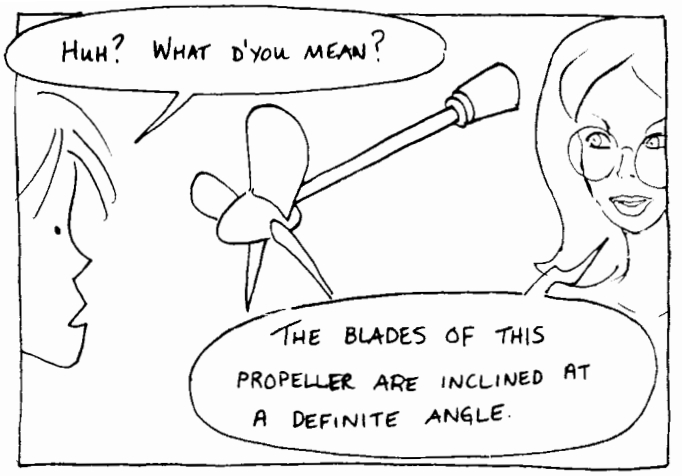


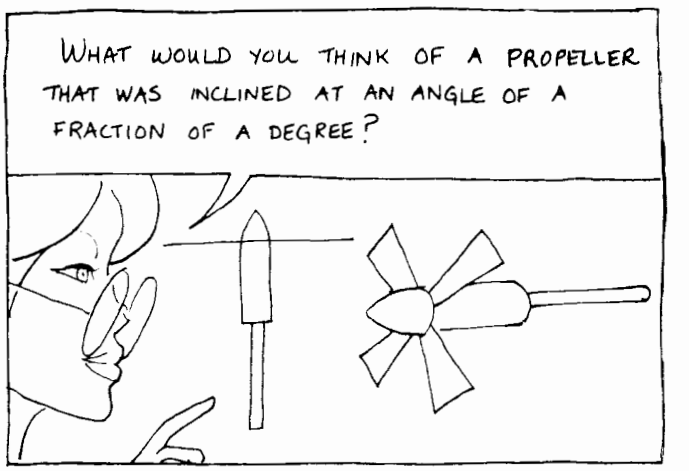


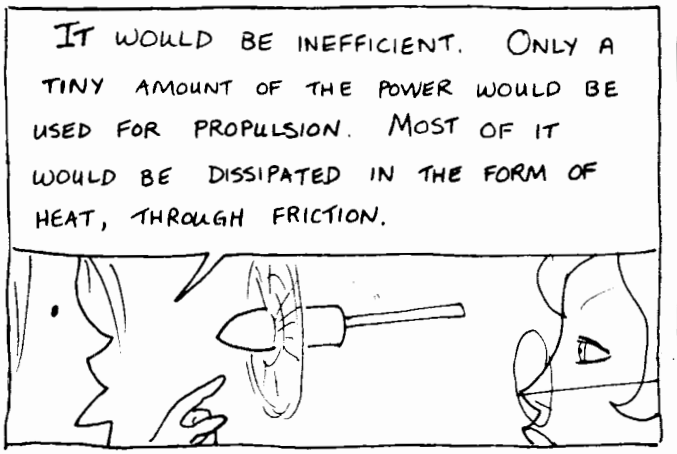


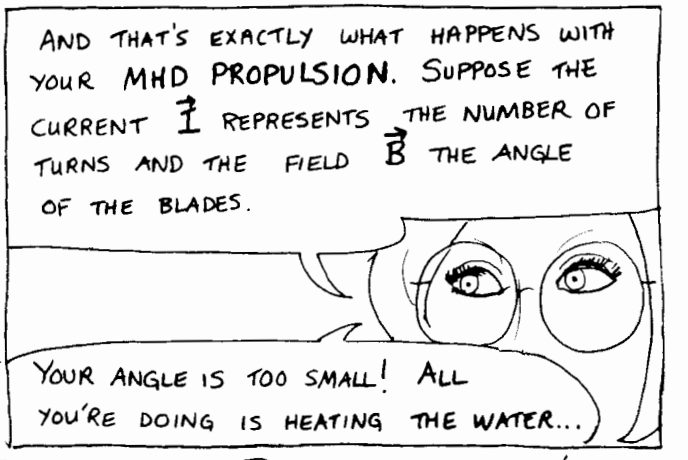
MHD EFFICIENCY

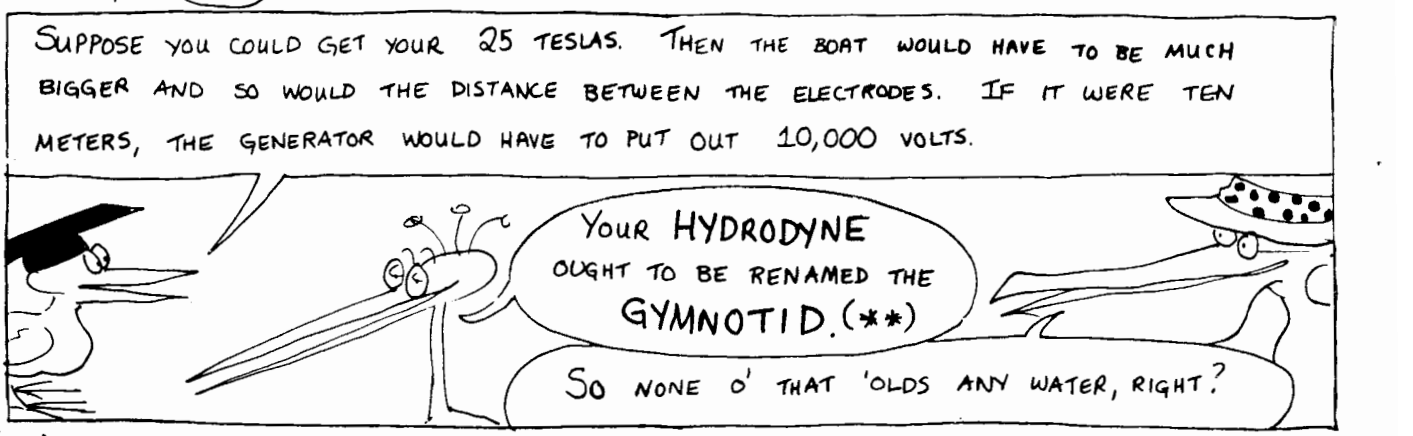
(*) SEE APPENDIX C (PAGE 71)







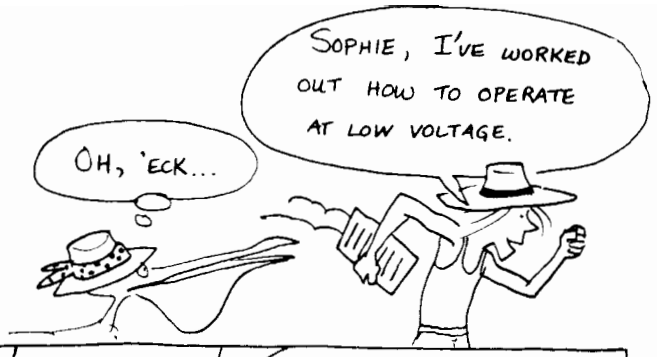


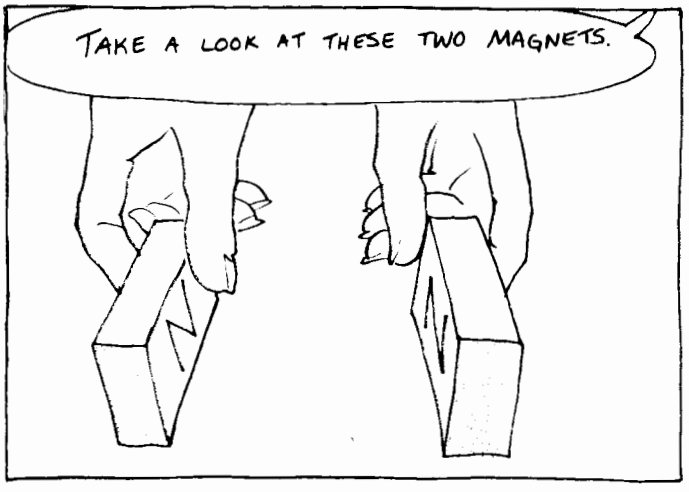


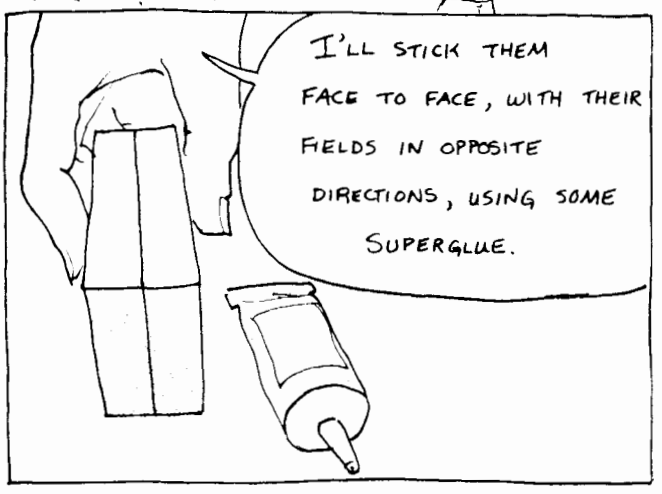
(*) SEE APPENDIX C (PAGE 71)

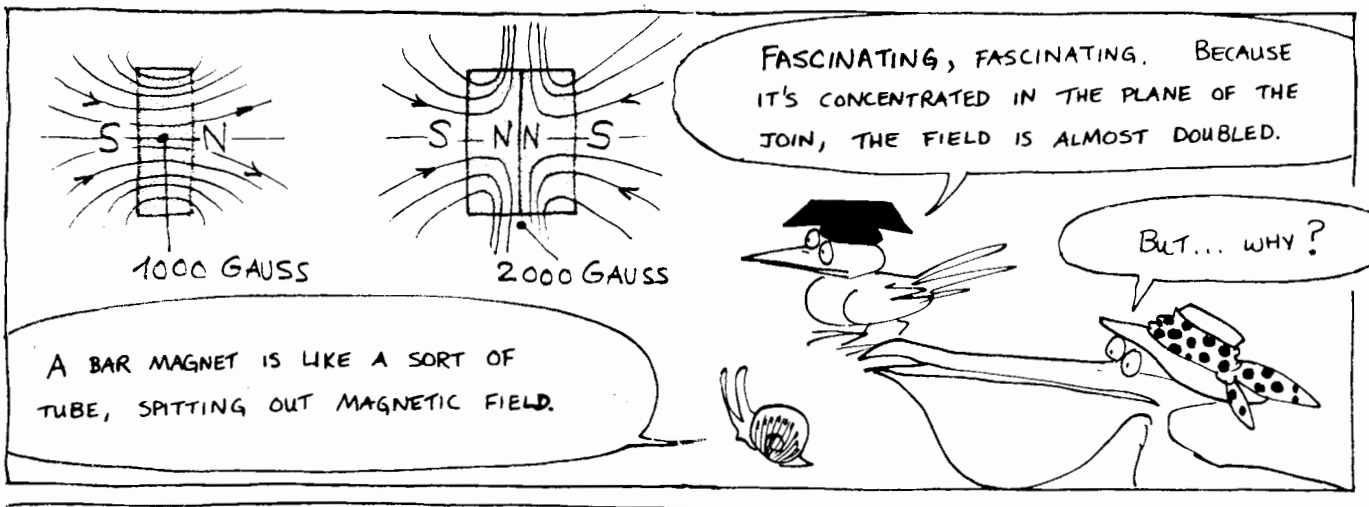
(**) A GYMNOTID IS A  ABLE TO PRODUCE AN ELECTRICAL DISCHARGE OF 300 VOLTS.

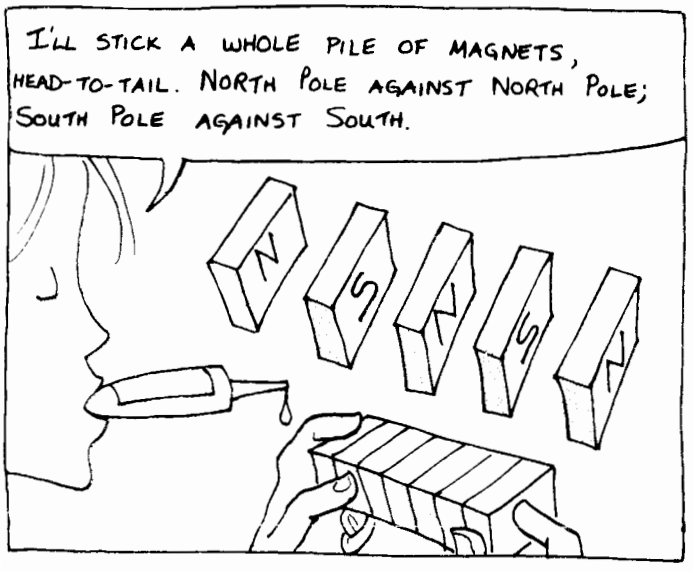
THE PARIETAL ACCELERATOR

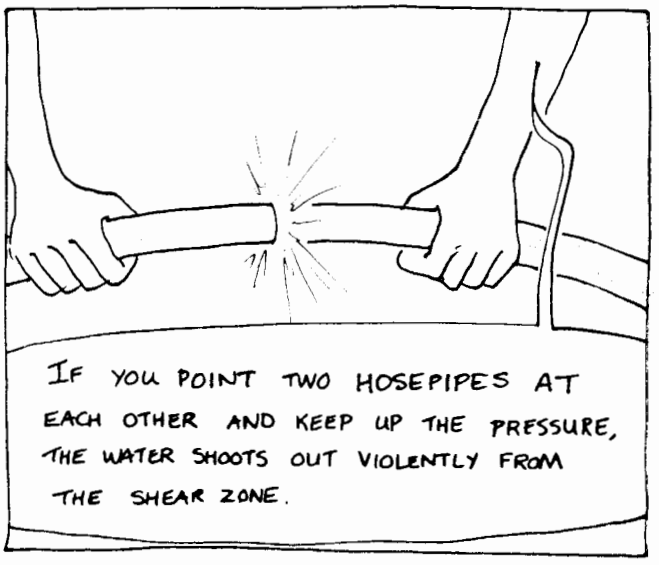


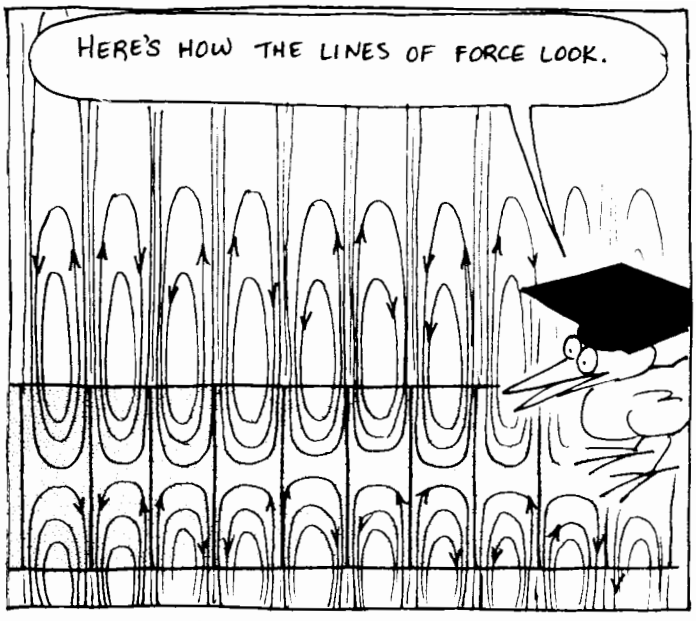


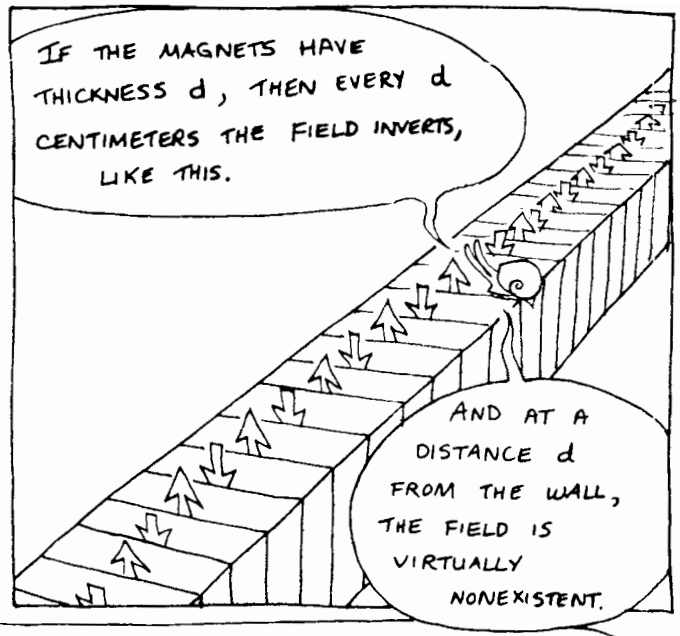




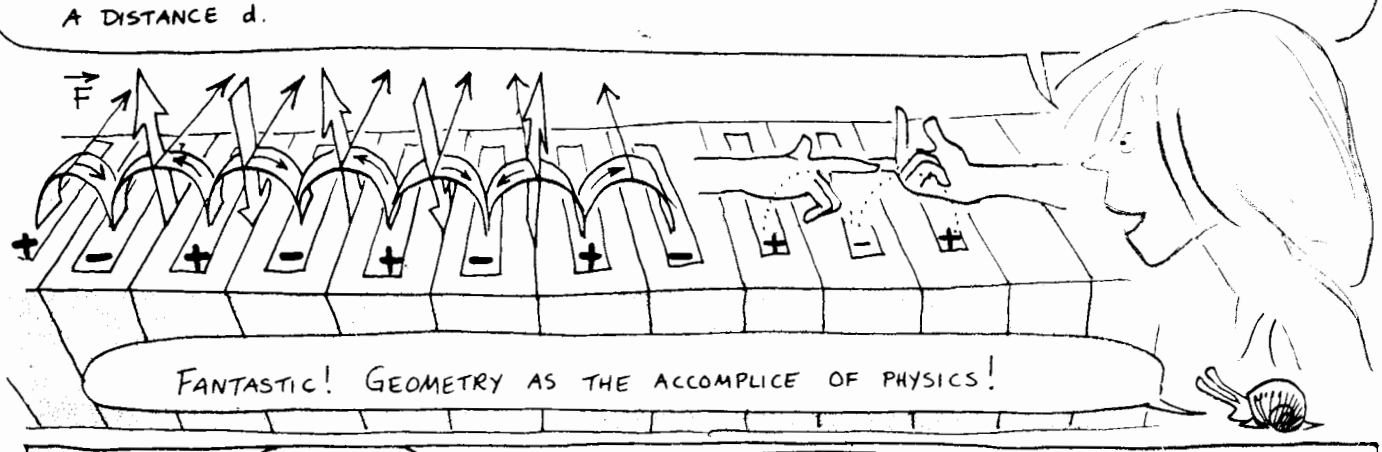


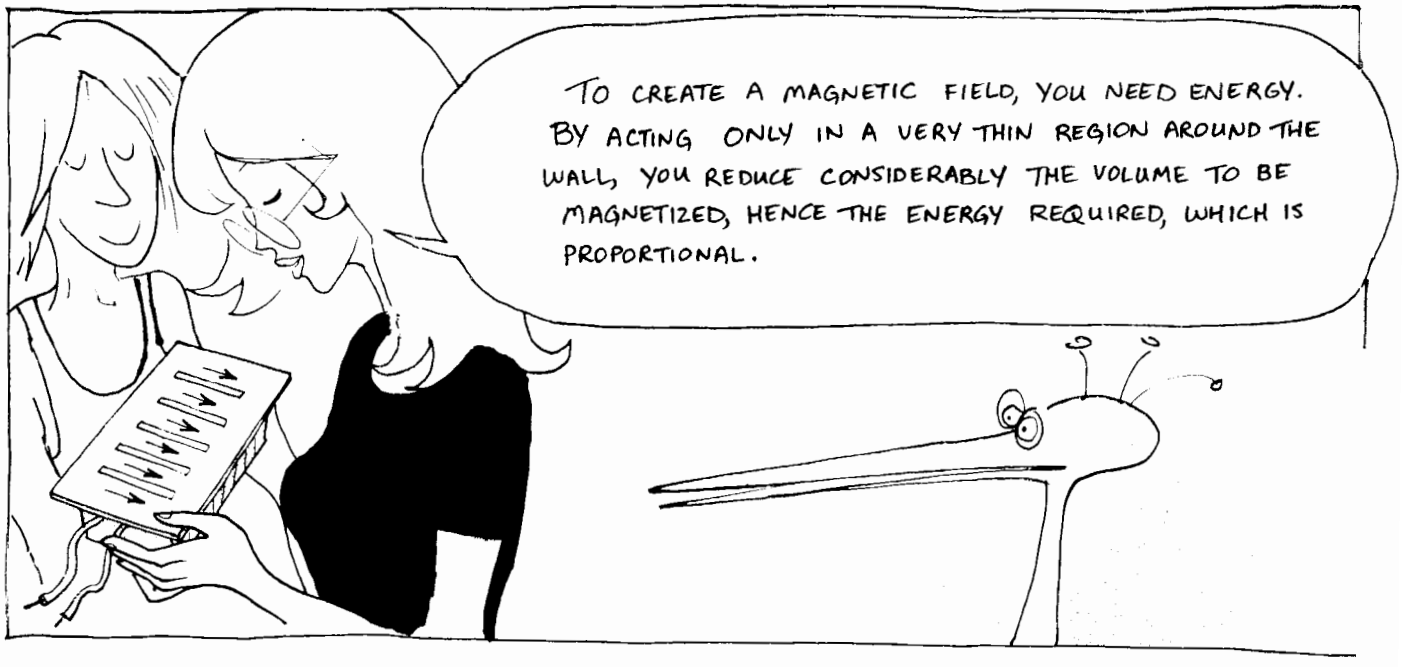




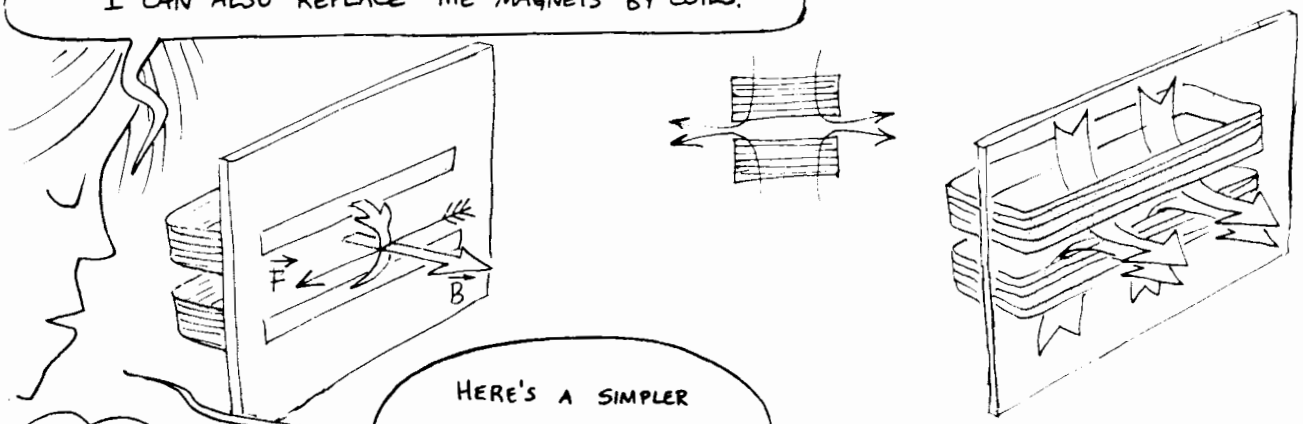


WATCH, NOW. I'VE ADDED SOME ELECTRODES, LIKE THIS, WITH ALTERNATING POLARITY. NOW, IF I APPLY THE **RIGHT-HAND RULE**, I SEE THAT I'VE CREATED A **FIELD OF FORCES, ALL PARALLEL AND IN THE SAME DIRECTION,** NEAR TO THE WALL, OUT TO A DISTANCE d.





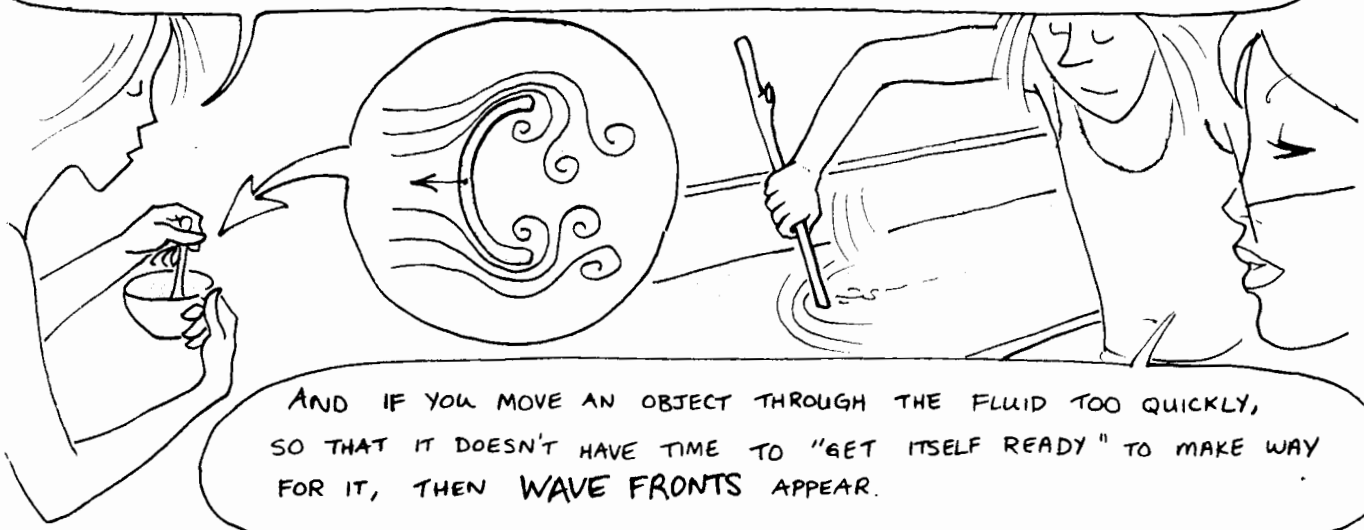
I CAN ALSO REPLACE THE MAGNETS BY COILS.



HERE'S A SIMPLER SYSTEM, USING TWO ELECTRODES.

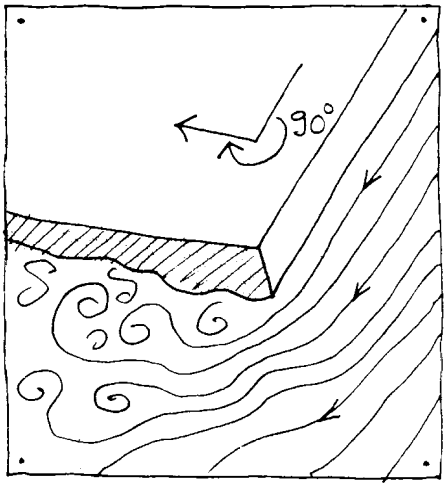
A NEW KIND OF FLUID MECHANICS

WHENEVER YOU MAKE A FLUID DO SOMETHING THAT MOVES IT, IT REACTS. FOR EXAMPLE, IF YOU TRY TO MAKE IT TWIST TOO ABRUPTLY, IT "COMES UNSTUCK."

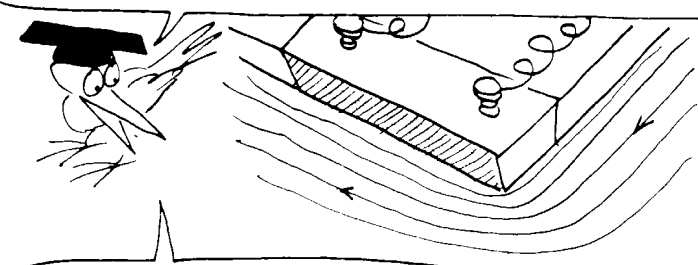


AND IF YOU MOVE AN OBJECT THROUGH THE FLUID TOO QUICKLY, SO THAT IT DOESN'T HAVE TIME TO "GET ITSELF READY" TO MAKE WAY FOR IT, THEN **WAVE FRONTS** APPEAR.

AND THAT'S HOW IT IS IF YOU LET THE FLUID DO AS IT PLEASES. BUT **MHD CHANGES RADICALLY ALL THE PARAMETERS OF THE PROBLEM.**



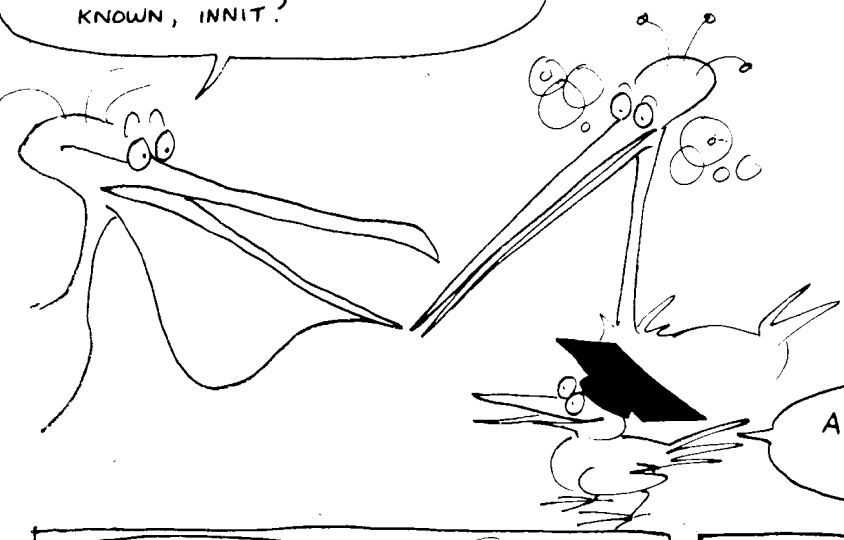
FOR EXAMPLE: IN CLASSICAL FLUID MECHANICS, A SHARP CORNER PRODUCES A LOSS OF ADHESION, GENERATING TURBULENCE.



A LITTLE BIT OF **MHD**, AND IT'S ALL HUNKY-DORY AGAIN.

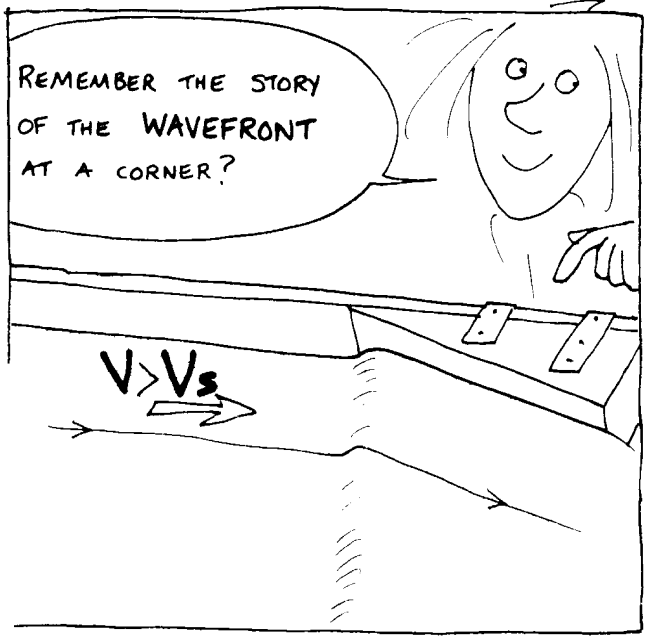
EITHER WAY, YOU WIN!

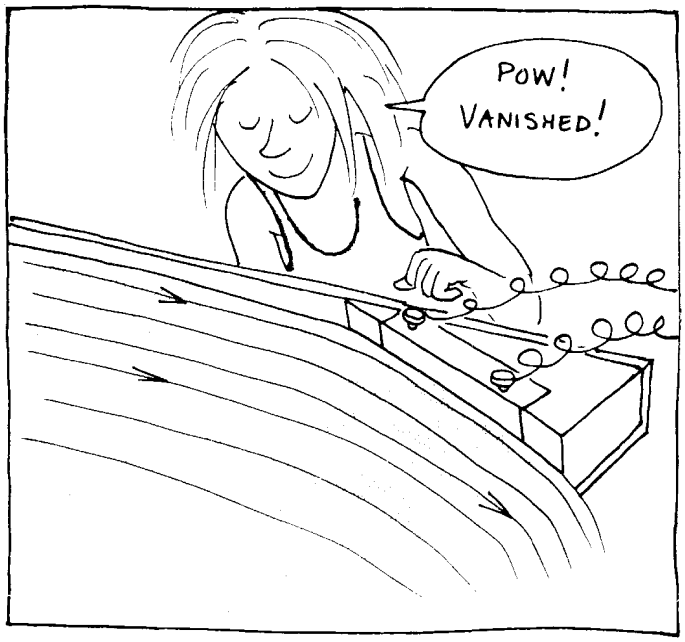
BUT... IT'S CRAZY! IT'S ALL KNOWN, INNIT?



A WHIFF OF MADNESS WAFTS THROUGH THIS TALE...

REMEMBER THE STORY OF THE **WAVEFRONT** AT A CORNER?



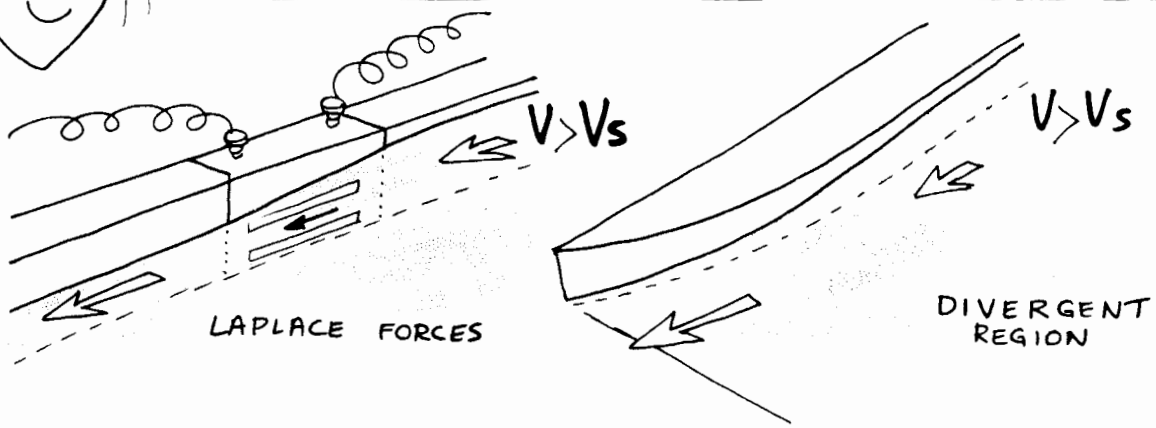


POW! VANISHED!

COMPRESSION WAVES EXPANSION WAVES

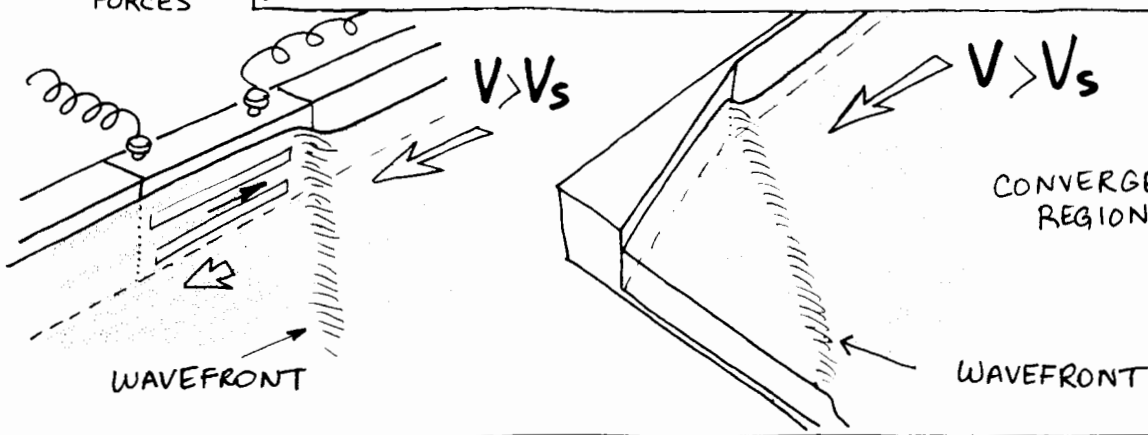
OH YES, LENNY – YOU'LL SEE. YOU AGREE THAT WHEN $V > V_s$, CHANGES IN DIRECTION OF A WALL CREATE EITHER A COMPRESSION OR AN EXPANSION. NOW, LOOK, THE MAGNETOHYDRODYNAMIC SYSTEM CREATES ABSOLUTELY IDENTICAL EFFECTS!

THE MHD ACCELERATOR, OR A DIVERGENT REGION, LEAD TO A LOWERING OF THE LEVEL OF THE WATER IN THE CANAL.



THE MHD DECELERATOR, OR A CONVERGENT REGION, LEAD TO A RISE IN THE LEVEL OF WATER IN THE CANAL.

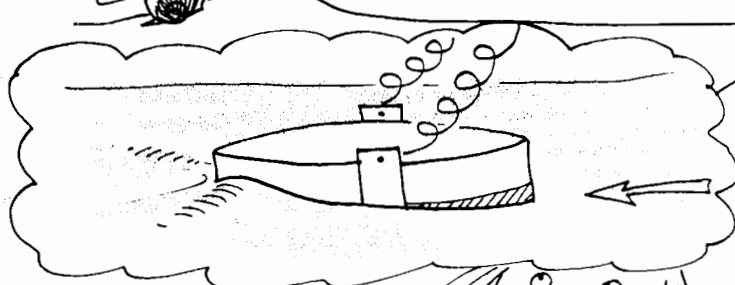
LAPLACE FORCES



SO IT OUGHT TO BE POSSIBLE TO ARRANGE FOR THE MUTUAL ANNIHILATION OF THE PHENOMENA OF COMPRESSION AND EXPANSION BY CANCELLING THOSE OF "NATURAL" ORIGIN — DUE TO THE WALLS — AGAINST LAPLACE FORCES OF "ARTIFICIAL" ORIGIN.

TO **REGULARIZE** THE FLOW AROUND THE HULL, YOU MUST SMOOTH OUT, AS FAR AS POSSIBLE, ANY VARIATIONS IN THE WATER LEVEL. WHERE A **WAVEFRONT** TENDS TO FORM, I ACCELERATE. AND TO AVOID AN **OVEREXPANSION**, AN **OVERACCELERATION**, IN SOME REGIONS, I SLOW IT DOWN.

IT'S AN APPLICATION OF MY FUNDAMENTAL PRINCIPLE, PURE AND SIMPLE: **PLEASE LEAVE THE FLUID IN THE STATE IN WHICH YOU WOULD WISH TO FIND IT.**

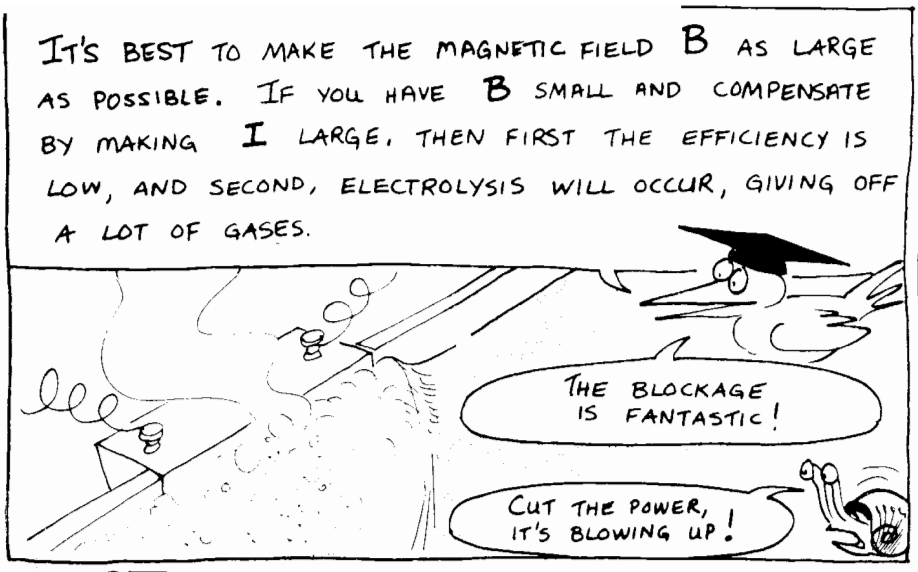


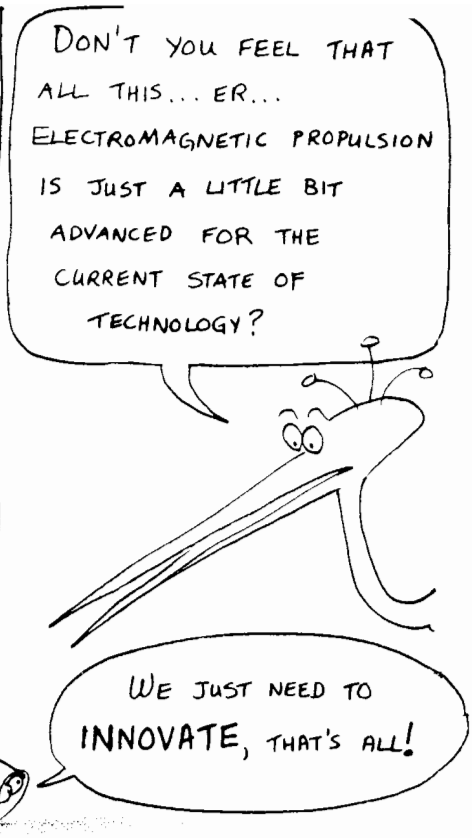
IN MY EXPERIMENT ON PAGE 28 I SUCCEEDED IN ANNIHILATING THE BOW WAVE. BUT THE STERN WAVE REMAINED — IN FACT IT WAS <u>REINFORCED</u>.

THE STERN WAVE OCCURRED PRECISELY BECAUSE YOU LOWERED THE WATER LEVEL TOO MUCH WHEN YOU ACCELERATED IT.

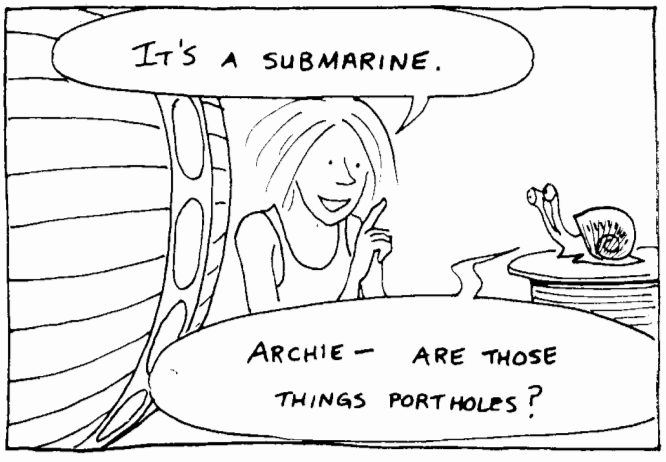

YOU'RE RIGHT. THE MAIN OBJECTIVE SHOULD BE TO KEEP THE HEIGHT OF THE WATER CONSTANT, AT THE NATURAL FLOTATION LINE. TO DO THAT, I'LL NEED A WHOLE MASS OF ELECTRODES, SOME ACCELERATING, SOME RETARDING.
ANOTHER APPLICATION OF TIRESIAS'S PRINCIPLE....
THAT'S RIGHT! SORT IT ALL OUT SO THAT YOU LEAVE THE FLUID IN THE STATE IN WHICH YOU WOULD WISH TO FIND IT... NO STERN WAVE!
BLOOMIN' MARVELOUS. TWENNY TESLAS WORF O' MAGNETIZATION, AN' ARCHIE'S KERNOO SKIMS FRU THE WATER WIVAHT WAVEFRONTS AN' WIVAHT ANY TURBULENCE. NO DAMAGE TER LANDIN' STAGES. WOT NEXT?
WOULDN'T IT BE EASIER JUST TO STAY FAR ENOUGH OUT TO SEA? DON'T YOU ALL HAVE MORE IMPORTANT THINGS TO DO?

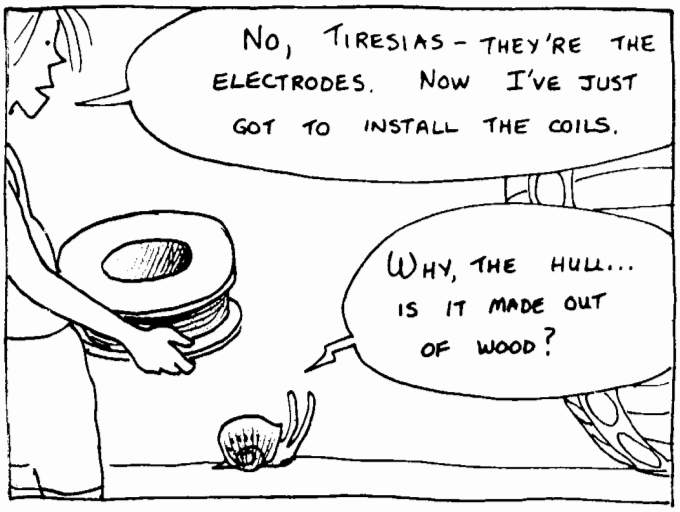
(*) SEE APPENDIX B (PAGE 71)

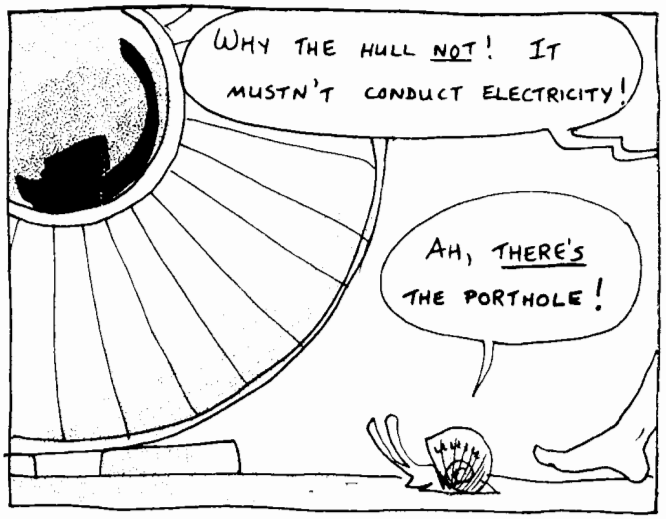


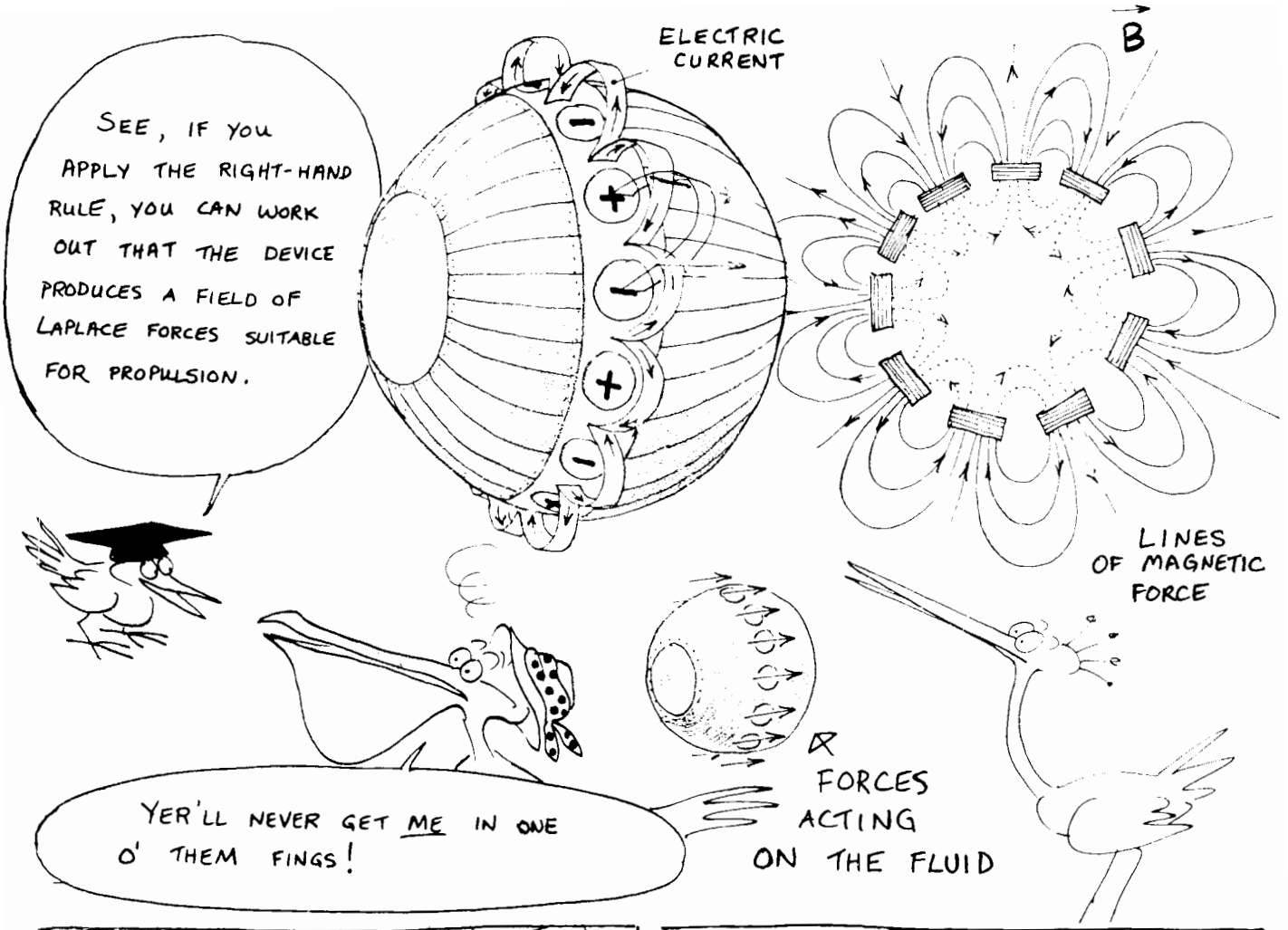


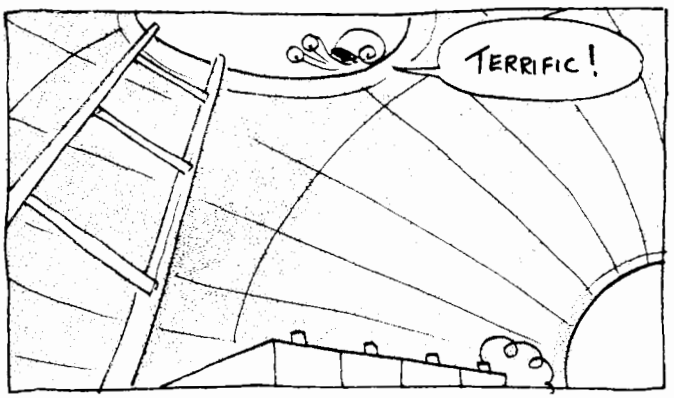
THE SCREWLESS SUBMARINE



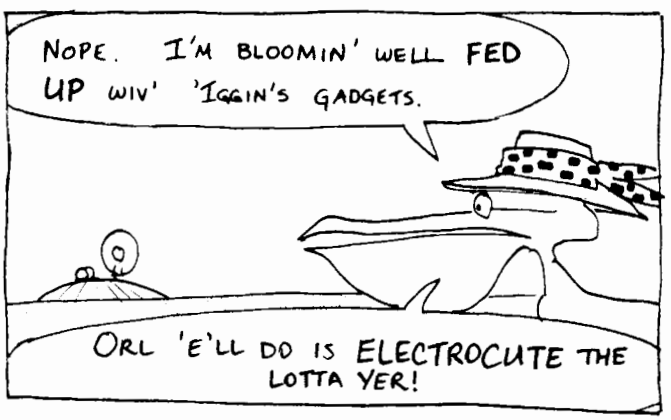


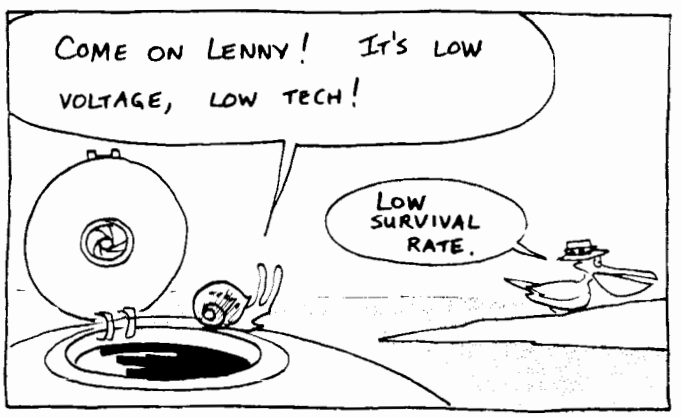


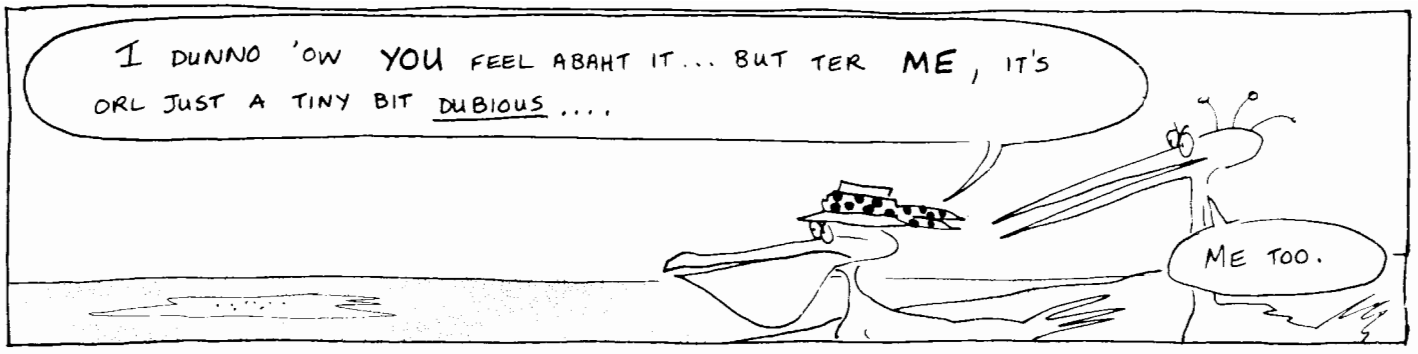

SEE, IF YOU APPLY THE RIGHT-HAND RULE, YOU CAN WORK OUT THAT THE DEVICE PRODUCES A FIELD OF LAPLACE FORCES SUITABLE FOR PROPULSION.
ELECTRIC CURRENT
B
LINES OF MAGNETIC FORCE
&
FORCES ACTING ON THE FLUID
YER'LL NEVER GET ME IN ONE O' THEM FINGS!

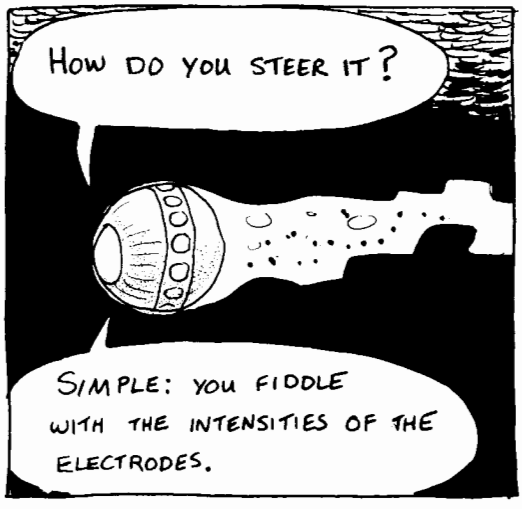

TERRIFIC!

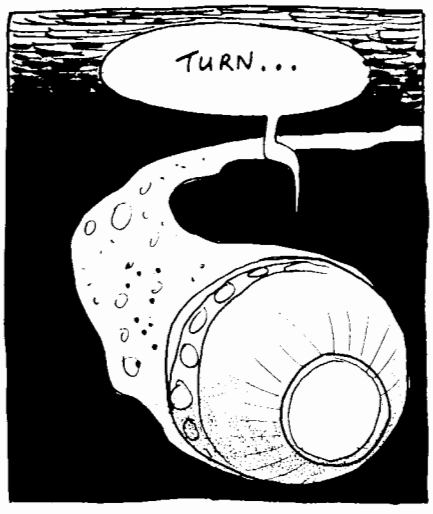

COME ON, LENNY! STOP MAKING FACES!
WE'RE GOING TO TRY OUT THE HYDRODYNE.

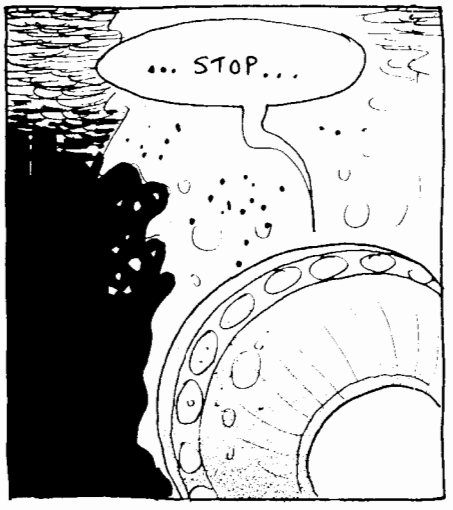

NOPE. I'M BLOOMIN' WELL FED UP WIV' 'IGGIN'S GADGETS.
ORL 'E'LL DO IS ELECTROCUTE THE LOTTA YER!

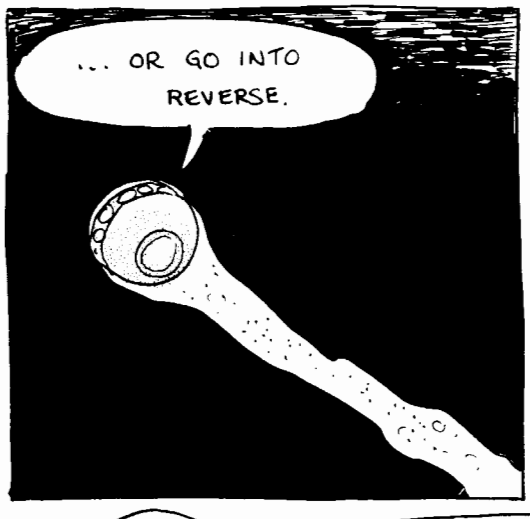

COME ON LENNY! IT'S LOW VOLTAGE, LOW TECH!
LOW SURVIVAL RATE.











(*) A SUPERCONDUCTING MATERIAL, COOLED TO VERY LOW TEMPERATURE (A FEW DEGREES KELVIN) CONDUCTS CURRENT WITHOUT ANY DISSIPATION BY HEATING. NO JOULE EFFECT.

THE FOLLOWING DAY

SUPERSONIC FLOW

– THE SHOCKWAVE THAT BROKE THE WINDOWS IS VERY SIMILAR TO THE BOW WAVE THAT SMASHED UP YOUR LANDING-STAGE.

– YOU MEAN, AIRPLANES MAKE WAVES?

– IN A MANNER OF SPEAKING, YES. BUT THEY DON'T MAKE SURFACE WAVES; THEY EMIT SOUND WAVES, WHICH TRAVEL AT THE SPEED OF SOUND V_S. (*) WHEN A BOAT TRAVELS AT A SPEED V GREATER THAN V_S IT PRODUCES WAVEFRONTS. BUT WHEN A PLANE TRAVELS FASTER THAN SOUND (GREATER THAN V_S) IT PRODUCES SHOCKWAVES.

– HOW CAN IT, WHEN THERE'S NO FREE SURFACE?

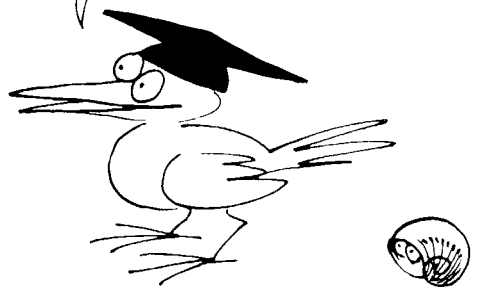
– THE DENSITY OF THE AIR PLAYS THE ROLE OF THE HEIGHT OF THE WATER. SURFACE WAVES TEND TO MAINTAIN A CONSTANT HEIGHT. SIMILARLY, SOUND WAVES TEND TO MAINTAIN A CONSTANT DENSITY. SHOCKWAVES ARE THE FRONTS WHERE DENSITY, PRESSURE, AND TEMPERATURE ARE MUCH HIGHER.

YOU CAN COMPARE THE MOTION OF MOLECULES TO A LOT OF BLINDFOLDED PEDESTRIANS, WANDERING ABOUT AT A SPEED V_S IN A TOTALLY DISORDERED FASHION, IN ONE PLACE, CONTINUALLY BUMPING INTO EACH OTHER (MOLECULAR COLLISIONS). AN OBJECT PENETRATING A GAS IS SIMILAR TO A BUS, RUNNING INTO THE CROWD AT A SPEED V. IF THIS IS LESS THAN V_S, THEN INFORMATION CAN PASS UPSTREAM (FORWARD). THE PEDESTRIANS, WARNED OF THE VEHICLE'S ARRIVAL BEFORE IT REACHES THEM, CAN MAKE WAY FOR IT. THAT'S ONE WAY TO VISUALIZE SUBSONIC FLOW.

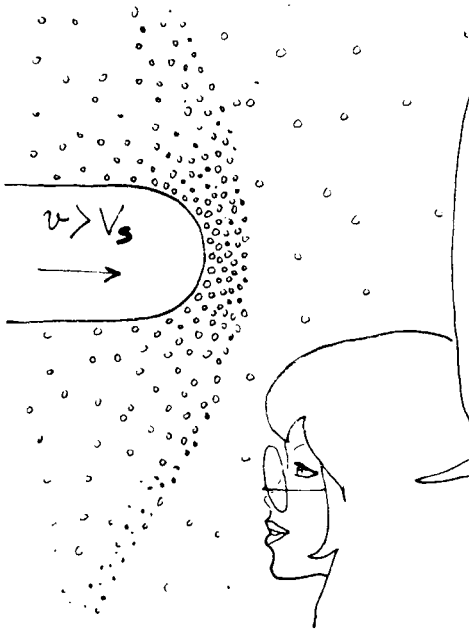
(*) SEE FLIGHT OF FANCY, SAME SERIES.

BUT WHAT HAPPENS WHEN V IS GREATER THAN V_S?

THE PEDESTRIANS – THE MOLECULES – ARE NO LONGER ABLE TO AVOID THE OBJECT **BEFORE** IT REACHES THEM, SO MAINTAINING A **CONSTANT DENSITY**. SO THE GAS (CROWD) TENDS TO ACCUMULATE AHEAD OF THE OBJECT, FORMING A SORT OF MOUND – AN ABRUPT INCREASE IN DENSITY.



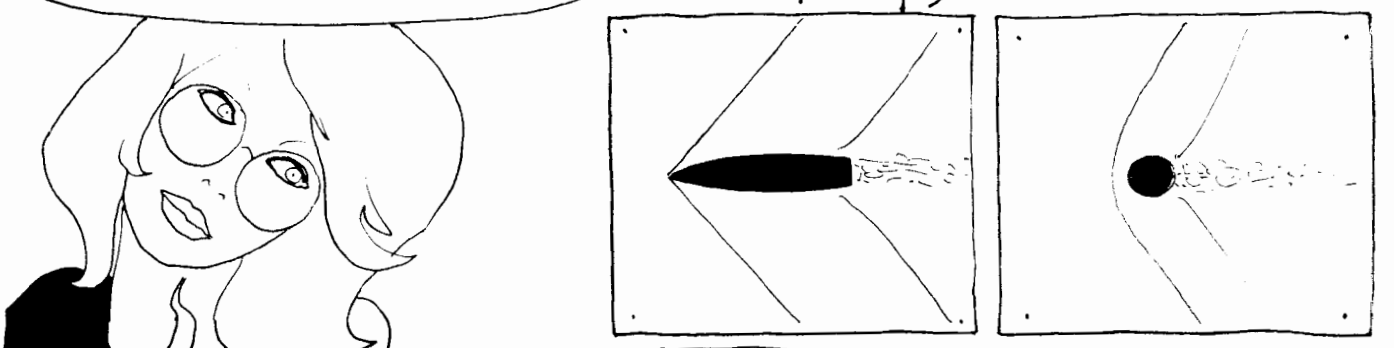
SHOCKWAVES



THIS PHENOMENON IS CALLED A SHOCKWAVE. HERE SOUND WAVES REPLACE SURFACE WAVES, OTHERWISE IT'S JUST THE SAME AS FOR A BOW WAVE. FRONTS OF DENSITY, PRESSURE, AND TEMPERATURE ARE INEVITABLY FORMED. THE SHOCKWAVE OCCURS WHEN THE SPEED V OF THE FLOW IS GREATER THAN THE SPEED OF SOUND V_S.

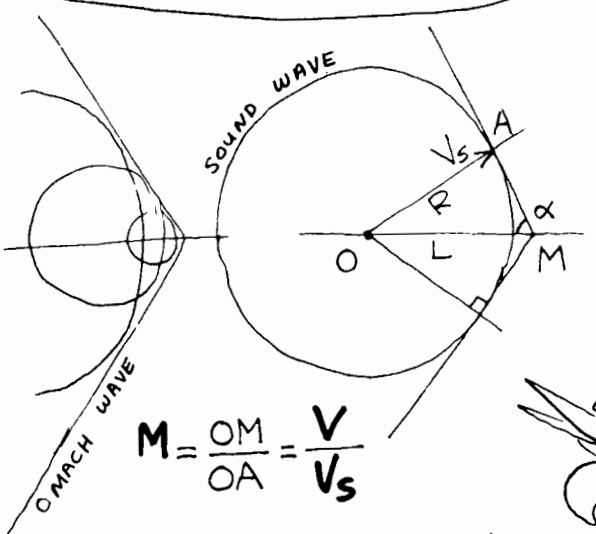
You mean to say that every time those hotshots at the Air Force Base decide to amuse themselves with some high-speed aerobatics, I have to lug a heap of replacement windows around the house!

Yeah, that figures!



So every object traveling at a supersonic speed (faster than sound) will have a **frontal** shockwave and a **rear** shockwave. On the left is a bullet, on the right a sphere.

Every object, even a grain of sand, projected at a speed $V > V_S$, creates a shock. The ratio $M = V/V_S$ is called the **Mach number.** And if the object is very small, the shockwave is called a **Mach wave.** (*)



$$M = \frac{OM}{OA} = \frac{V}{V_S}$$

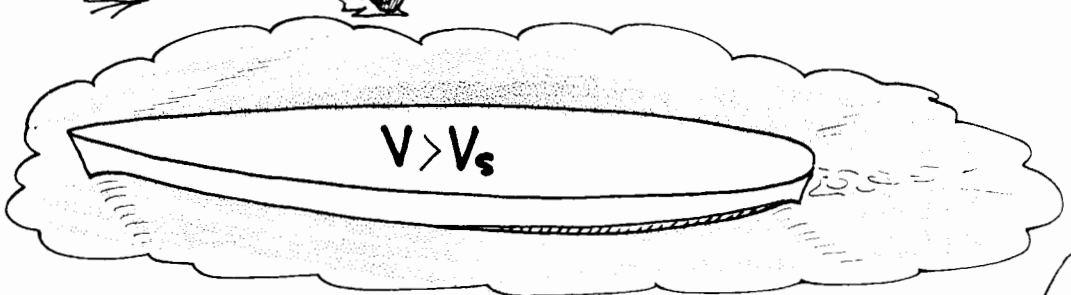
(*) See Appendix A (page 71).

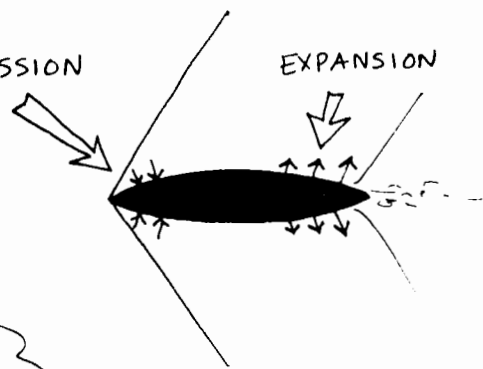

SOPHIE'S RIGHT, YOU KNOW, MAX. THE FLOW OF A LIQUID WITH A FREE SURFACE CLOSELY RESEMBLES THE SUPERSONIC FLOW OF A GAS. I THINK WE'D BETTER TAKE ANOTHER LOOK AT PAGE 15 TO REMIND OURSELVES ABOUT THE EFFECT OF SLOWER OR FASTER MOTION ON THE SHAPE OF THE SHOCK.
MACH 1.5
MACH 5
BETWEEN THE WARS PEOPLE DIDN'T HAVE COMPUTERS, AND THEY CALCULATED THE SHAPES OF SHOCKWAVES USING A "HYDRAULIC ANALOGY."
YIKES! A WATER-COMPUTER?
IN FACT THERE'S A STRONG SIMILARITY BETWEEN THE MATHEMATICAL EQUATIONS DESCRIBING THE TWO SYSTEMS, WITH THE HEIGHT OF THE WATER CORRESPONDING TO THE DENSITY OF THE GAS.
GREAT. NOW, ALL I NEED TO STUDY THAT IS A SUPERSONIC WIND-TUNNEL.
OH, WONDERFUL!
HAH! YOU WON'T BE ABLE TO BUILD THAT IN YOUR BATHROOM!
A WIND-TUNNEL, THAT'S SOMEFINK ELSE.
YER NEEDS RUDDY GREAT COMPRESSORS AN' MASSES OF ENERGY!
PERHAPS YOU OUGHT TO APPLY FOR A GRANT FROM THE NATIONAL SCIENCE FOUNDATION.

THE SOUND BARRIER
THE HEAT BARRIER

WITH A SUPERSONIC WIND-TUNNEL, IT'S POSSIBLE TO OBSERVE A NUMBER OF DIFFERENT PHENOMENA. PRIMARILY, THE PASSAGE THROUGH THE SOUND BARRIER ($V = V_s$), ACCOMPANIED BY THE APPEARANCE OF A WAVE TRAIN WHICH IS SUPERIMPOSED ON THE TRAIN DUE TO FRICTIONAL DRAG.

WHAT'S THAT IN CONCRETE TERMS?





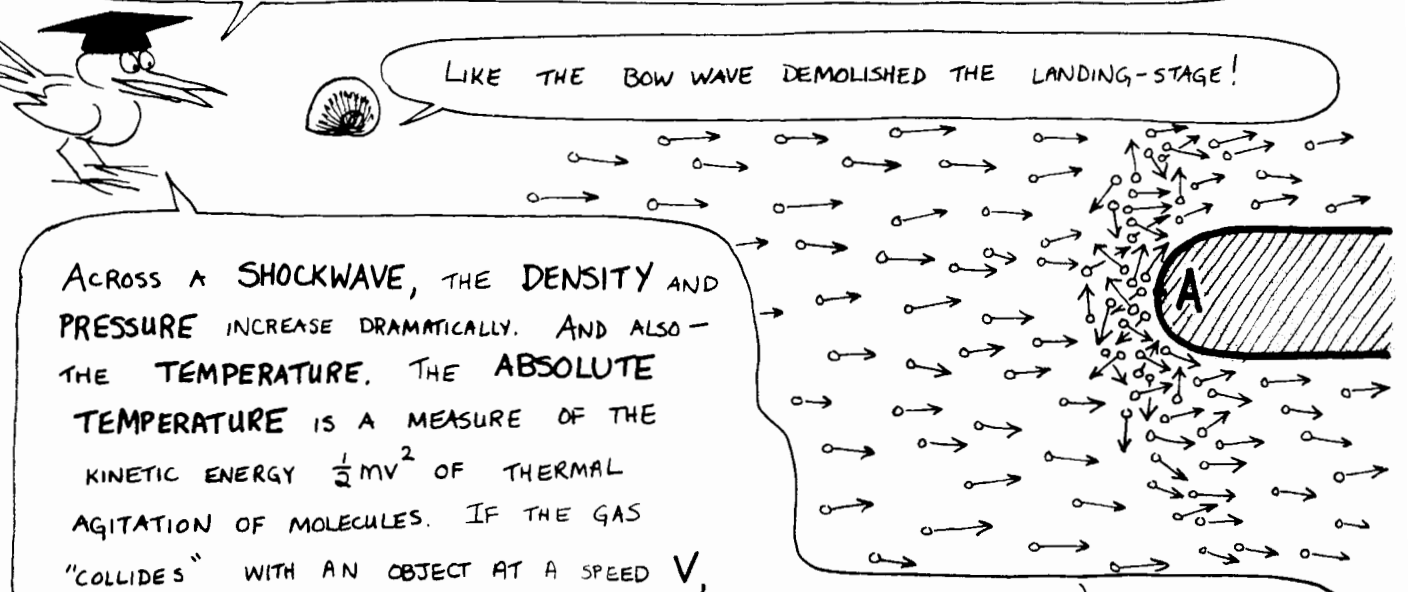
IN HYDRODYNAMICS, THE APPEARANCE OF WAVEFRONTS AFFECTS THE BALANCE OF PRESSURES ON THE HULL, REDUCING THE EFFICIENCY. IT'S THE SAME IN SUPERSONIC AERODYNAMICS.

IT'S NOISY, IT'S USELESS, AND IT WASTES ENERGY.

DESPITE ITS SLIM SHAPE, DESIGNED TO REDUCE THIS WAKE, THE CONCORDE SPENDS 40% OF ITS ENERGY CREATING SHOCKWAVES.

IF YOU WANTED TO OVERFLY AN INHABITED REGION AT LOW ALTITUDE AT **MACH** 5 OR 6, EVERYBODY'S ROOF WOULD FALL IN.

LIKE THE BOW WAVE DEMOLISHED THE LANDING-STAGE!



ACROSS A **SHOCKWAVE**, THE **DENSITY** AND **PRESSURE** INCREASE DRAMATICALLY. AND ALSO — THE **TEMPERATURE**. THE **ABSOLUTE TEMPERATURE** IS A MEASURE OF THE KINETIC ENERGY $\frac{1}{2}mV^2$ OF THERMAL AGITATION OF MOLECULES. IF THE GAS "COLLIDES" WITH AN OBJECT AT A SPEED **V**, THEN AT THE STATIONARY POINT **A** (WHERE THE GAS STOPS COMPLETELY) ALL OF THIS ENERGY IS CONVERTED INTO THERMAL AGITATION. SO AT THE POINT **A** THE **STOPPING TEMPERATURE** VARIES AS THE SQUARE OF THE SPEED **V**.

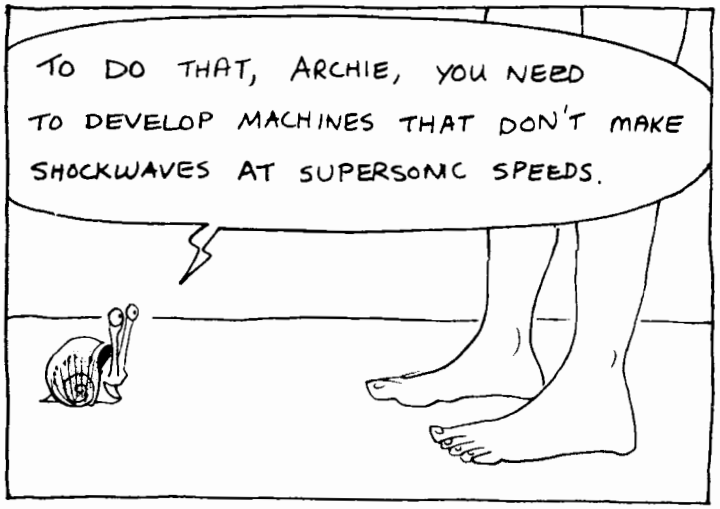
IS A WARM NOSE A SIGN OF HEALTH?

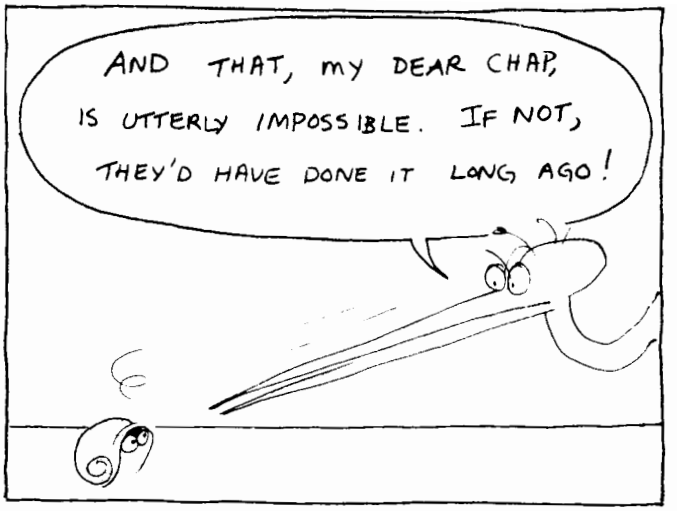
THIS PHENOMENON, WHICH ONLY BECOMES NOTICEABLE ABOVE MACH 2, IMPOSES A SERIOUS CONSTRAINT ON AIRCRAFT, KNOWN AS THE **HEAT BARRIER**.

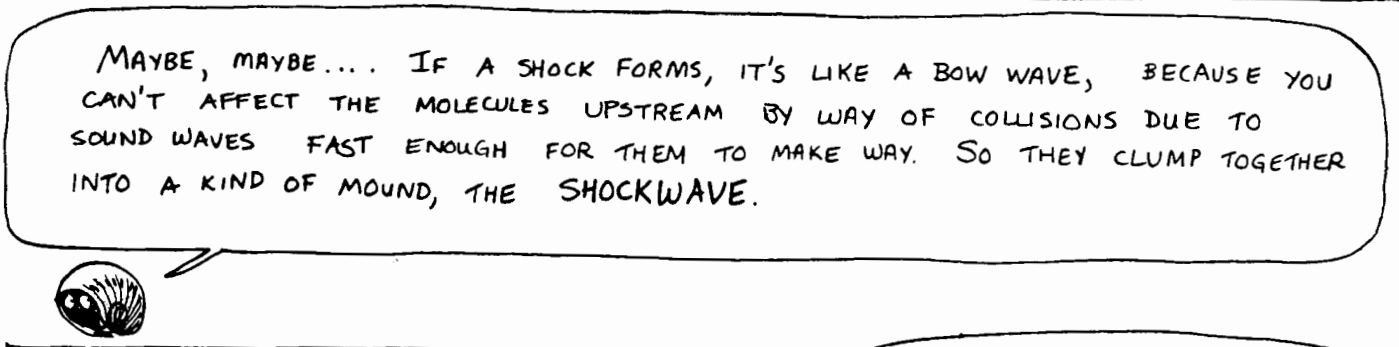
FER A GIVEN SPEED, THE FICKER THE AIR, THE 'OTTER EVERYFINK GETS.

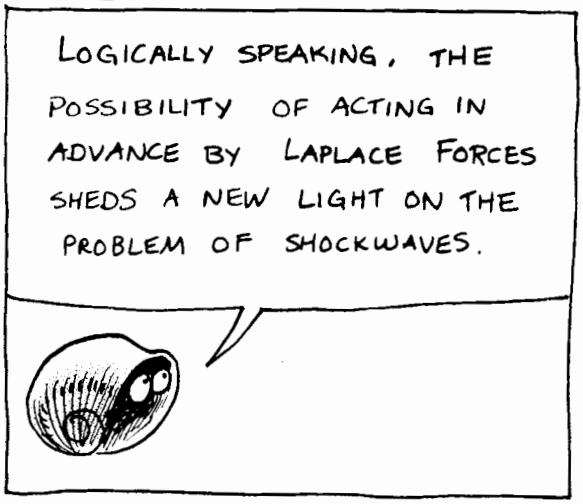
WHICH MEANS THAT HYPERSONIC SPEEDS AT LOW ALTITUDES ARE AN IMPOSSIBILITY!

YEAH, SURE. BUT LOW-ALTITUDE SUPERSONIC FLIGHT IS ALL TOO POSSIBLE! ISN'T THERE SOME WAY TO INVENT SUPERSONIC AIRCRAFT THAT DON'T SMASH WINDOWS?...

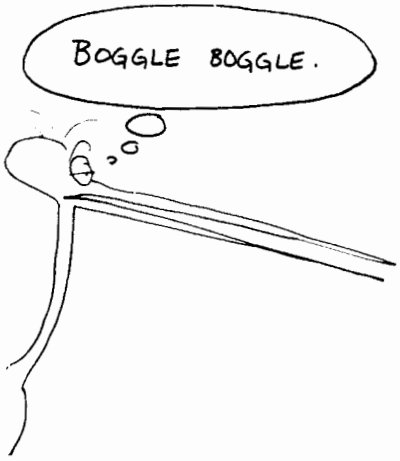

TO DO THAT, ARCHIE, YOU NEED TO DEVELOP MACHINES THAT DON'T MAKE SHOCKWAVES AT SUPERSONIC SPEEDS.

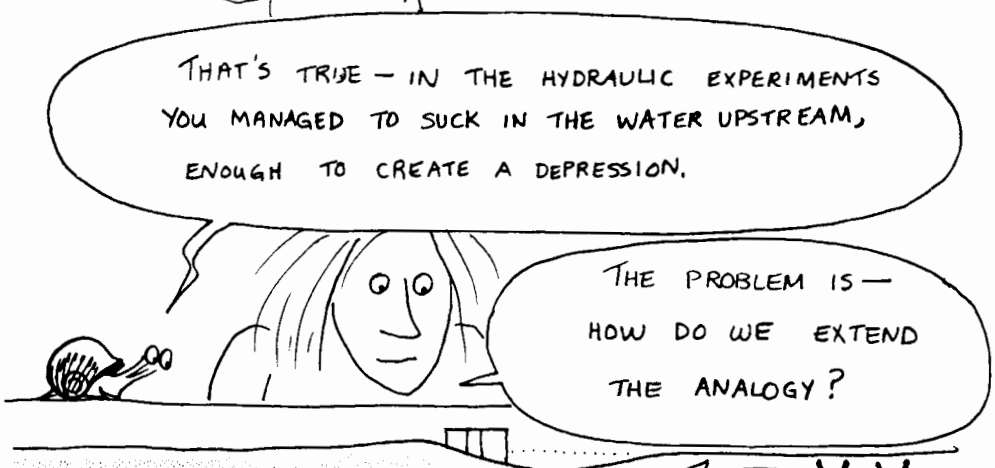

AND THAT, my DEAR CHAP, IS UTTERLY IMPOSSIBLE. IF NOT, THEY'D HAVE DONE IT LONG AGO!


MAYBE, MAYBE.... IF A SHOCK FORMS, IT'S LIKE A BOW WAVE, BECAUSE YOU CAN'T AFFECT THE MOLECULES UPSTREAM BY WAY OF COLLISIONS DUE TO SOUND WAVES FAST ENOUGH FOR THEM TO MAKE WAY. SO THEY CLUMP TOGETHER INTO A KIND OF MOUND, THE SHOCKWAVE.

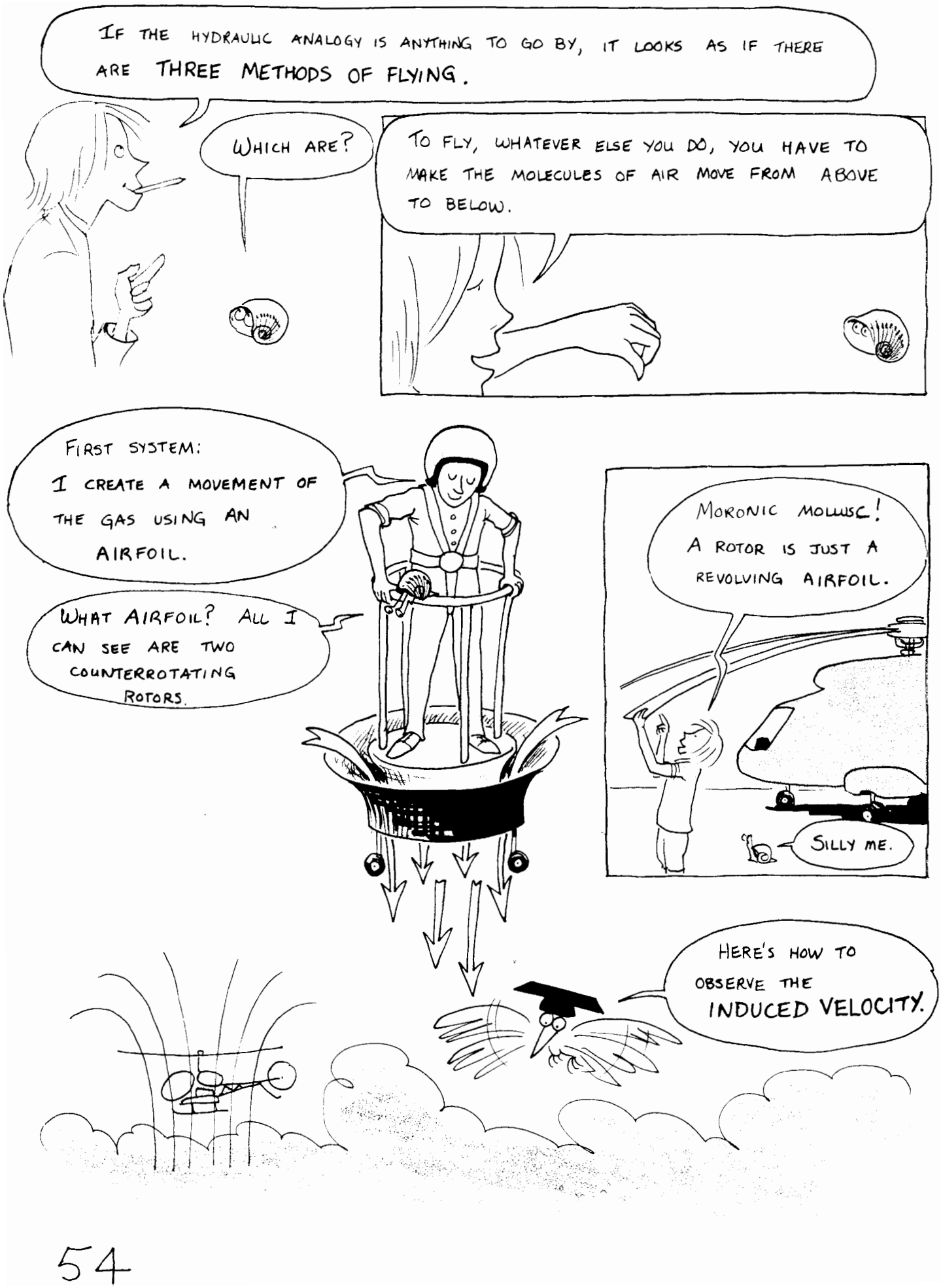

LOGICALLY SPEAKING, THE POSSIBILITY OF ACTING IN ADVANCE BY LAPLACE FORCES SHEDS A NEW LIGHT ON THE PROBLEM OF SHOCKWAVES.


TIRESIAS, TAKE A LOOK AT THIS PHOTO OF THE MHD FLOW ON PAGE 30, ROUND A CYLINDER. WOULDN'T YOU SAY IT'S RATHER SIMILAR TO A SUCTION EFFECT? HMMM...?


BOGGLE BOGGLE.


THAT'S TRUE — IN THE HYDRAULIC EXPERIMENTS YOU MANAGED TO SUCK IN THE WATER UPSTREAM, ENOUGH TO CREATE A DEPRESSION.
THE PROBLEM IS — HOW DO WE EXTEND THE ANALOGY?

V>Vs


IF THE HYDRAULIC ANALOGY IS ANYTHING TO GO BY, IT LOOKS AS IF THERE ARE THREE METHODS OF FLYING.
WHICH ARE?
TO FLY, WHATEVER ELSE YOU DO, YOU HAVE TO MAKE THE MOLECULES OF AIR MOVE FROM ABOVE TO BELOW.
FIRST SYSTEM: I CREATE A MOVEMENT OF THE GAS USING AN AIRFOIL.
WHAT AIRFOIL? ALL I CAN SEE ARE TWO COUNTERROTATING ROTORS.
MORONIC MOLLUSC! A ROTOR IS JUST A REVOLVING AIRFOIL.
SILLY ME.
HERE'S HOW TO OBSERVE THE INDUCED VELOCITY.


SECOND SYSTEM: ACCELERATE A GAS THAT YOU PRODUCE YOURSELF.
FFFFUSCHHHH
BUT WHAT'S THE THIRD SYSTEM?
TO MY THINKING, IT'S TO SUCK IN THE AIR FROM BELOW USING LAPLACE FORCES.
DID YOU HEAR WHAT I HEARD?
YEAH... ARCHIE AN' TIRESIAS BOFE. IT'S A CRYIN' SHAME!
THEY'VE BOTH GONE COMPLETELY POTTY, THE PAIR OF THEM, I DO DECLARE!
AND SOPHIE, NO DOUBT, AT THE BEACH....
AT LEAST MAX 'AS A BIT 'O SENSE.
WHAT'S UP WITH YOU?
ARCHIE'S GOT SOME CRAZY IDEA IN 'IS 'EAD... ABAHT FLYIN' WIV H'ELECTRICITY.
I POINTED OUT TO LENNY MYSELF, JUST NOW, THAT IT'S IMPOSSIBLE, BECAUSE AIR WON'T CONDUCT ELECTRICITY.
IT'S AN INSULATOR.

HOLD YOUR HORSES! THAT DEPENDS ON THE SIZE OF THE ELECTRIC FIELD YOU APPLY. THAT IS, THE RATIO BETWEEN THE TENSION AT THE ELECTRODES AND THE DISTANCE BETWEEN THEM!! IF YOU USE THREE THOUSAND VOLTS PER MILLIMETER, IT CRACKLES AWAY LIKE MAD!

SO WHEN'S THE ELECTRIC CONCORDE COMIN', EH?

ELECTRODES

SOLENOIDS

I
B
F

YOU SEE, WITH A MAGNETIC FIELD B OF 4 TESLAS (40,000 GAUSS) (*) AND A CURRENT DENSITY OF ONE AMPERE PER SQUARE CENTIMETER (TEN THOUSAND AMPERES PER SQUARE METER) YOU GET A LAPLACE FORCE OF 40,000 NEWTONS PER CUBIC METER. ABOUT FOUR TONS PER CUBIC METER. IF THE MOTOR HAS A USEFUL VOLUME OF ONE CUBIC METER, IT PROVIDES FOUR TONS OF THRUST.

FOUR TONS!

'ANG ON! YER BLINKIN' DREAMIN' AGAIN! THREE THOUSAND VOLTS PER MILLIMETER... THAT'S GETTIN' ON FER A COOL MILLYON VOLTS PER METER!...

FOR LAPLACE FORCES, THAT'S MINDBOGGLING!...

I KNOW A STRIKING APPLICATION OF LAPLACE FORCES.

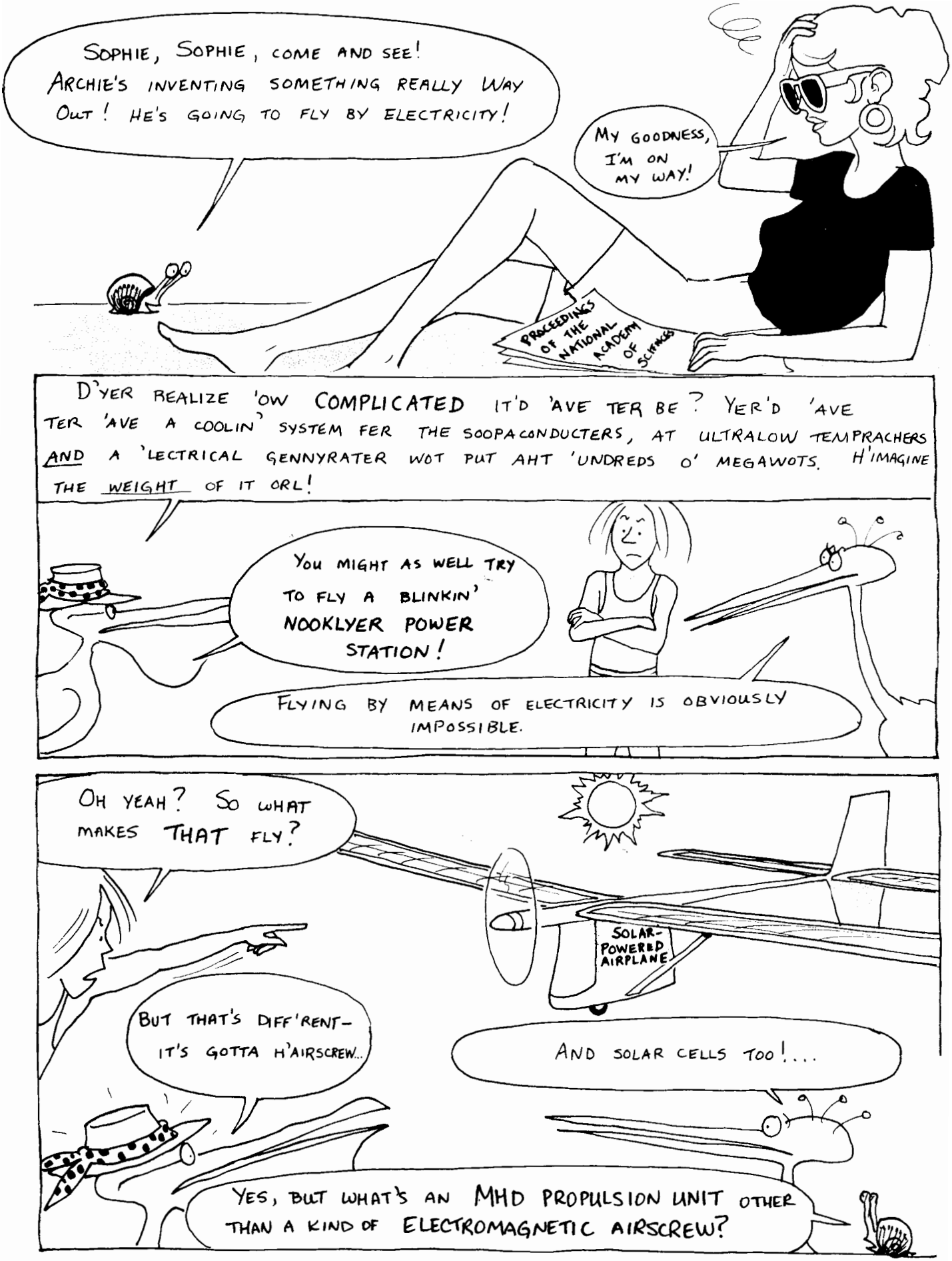
HMMM? WHAT?

THUNDER.

THUNDER?

I 'OPE YER GOT A REAL BANG OUTTA THAT!

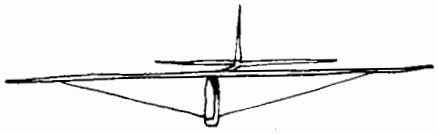
(*) ABOUT 100 TIMES MORE THAN THAT OF AN ORDINARY MAGNET.


SOPHIE, SOPHIE, COME AND SEE! ARCHIE'S INVENTING SOMETHING REALLY WAY OUT! HE'S GOING TO FLY BY ELECTRICITY!
MY GOODNESS, I'M ON MY WAY!
PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES
D'YER REALIZE 'OW COMPLICATED IT'D 'AVE TER BE? YER'D 'AVE TER 'AVE A COOLIN' SYSTEM FER THE SOOPACONDUCTERS, AT ULTRALOW TEMPRACHERS AND A 'LECTRICAL GENNYRATER WOT PUT AHT 'UNDREDS O' MEGAWOTS. H'IMAGINE THE WEIGHT OF IT ORL!
YOU MIGHT AS WELL TRY TO FLY A BLINKIN' NOOKLYER POWER STATION!
FLYING BY MEANS OF ELECTRICITY IS OBVIOUSLY IMPOSSIBLE.
OH YEAH? SO WHAT MAKES THAT FLY?
SOLAR-POWERED AIRPLANE
BUT THAT'S DIFF'RENT— IT'S GOTTA H'AIRSCREW..
AND SOLAR CELLS TOO!....
YES, BUT WHAT'S AN MHD PROPULSION UNIT OTHER THAN A KIND OF ELECTROMAGNETIC AIRSCREW?

TO FLY, YOU NEED ENERGY. IT DOESN'T MATTER MUCH WHAT FORM THE ENERGY TAKES - CHEMICAL, ELECTRICAL - AS LONG AS THERE'S ENOUGH OF IT.

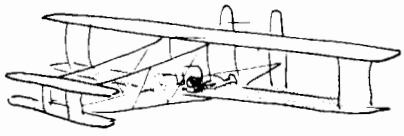
WHEN YOU LOOK AT THE BASICS, FLYING IS REALLY JUST A MATTER OF THE POWER-TO-WEIGHT RATIO FOR A GIVEN SPEED.

40 KM/HR MAN-POWERED PLANE (OR ELECTRIC)



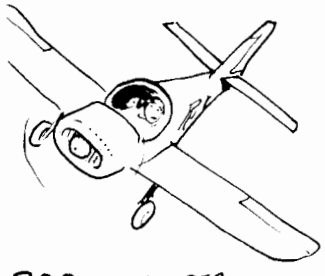
10 WATTS PER KILOGRAM

60 KM/HR THE WRIGHT BIPLANE (LOW-TECH)



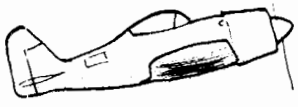
100 WATTS PER KILOGRAM

250 KM/HR LIGHT AIRCRAFT



300 WATTS PER KILOGRAM

700 KM/HR WORLD WAR II FIGHTER PLANE

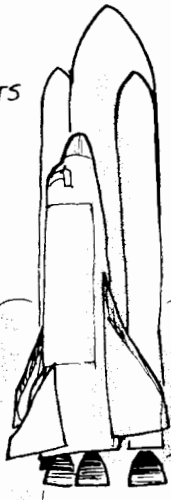


800 WATTS PER KILOGRAM

2700 KM/HR FIGHTER PLANE OF THE NEXT (AND LAST) WORLD WAR

5000 WATTS PER KILOGRAM

20,000 WATTS PER KILOGRAM



THE SPACE SHUTTLE!

'ANG ON, 'ANG ON, 'OLD YER 'ORSES. DON'T A NOOKLYER POWER STATION PRODUCE A KILLERWOT O' H'ELECTRICKLE H'ENERGY PER KILLERGRAM.? BY **YOUR** ARGUMENT H'IT OUGHTA **TAKE OFF** OF ITS OWN ACCORD!

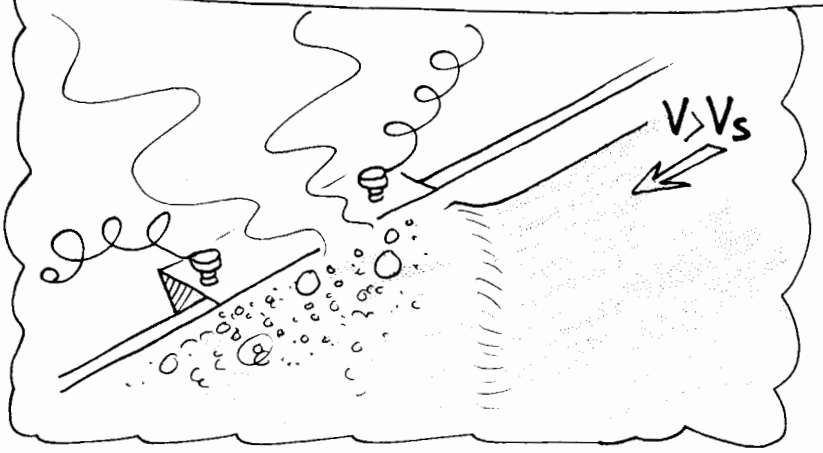
TEN TONS FOR A HUNDRED MEGAWATTS — IT'S IMPOSSIBLE!

WELL? SOPHIE?

CONFOUND THAT HIGGINS! IT'S FINALLY BEGINNING TO LOOK AS IF YOU'VE GOT TO EXTEND TO GASES THE IDEA WE REACHED FOR FLOWS OF A LIQUID WITH A FREE SURFACE: THE **INTERACTION CRITERION** AND ITS EFFECTS ON **MHD EFFICIENCY**. THERE MUST BE A SNAG SOMEWHERE — I WONDER WHAT IT IS?

WELL?

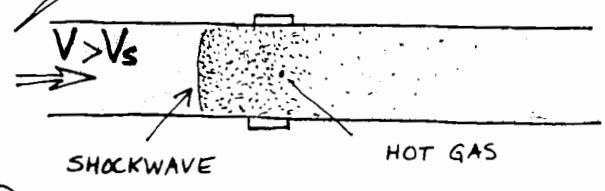
IN THE EXPERIMENT ON PAGE 43, **TOO STRONG** AN APPLICATION OF ENERGY PRODUCED A **BLOCKAGE**.



THERMAL BLOCKAGE

IS IT POSSIBLE THAT A SIMILAR PHENOMENON IN A GAS MIGHT PREVENT THE MHD ACTION?

IN FACT, YOU CAN BLOCK A SUPERSONIC FLOW OF A GAS BY WAY OF HEAT, VIA THE JOULE EFFECT. IN A PURELY ELECTRICAL DISCHARGE (NO MAGNETIC FIELD) THE BUBBLE OF HOT GAS BEHAVES LIKE A TRAFFIC JAM, AND A SHOCKWAVE FORMS.



SO ARCHIE'S EXPERIMENT IS DOOMED TO FAILURE?

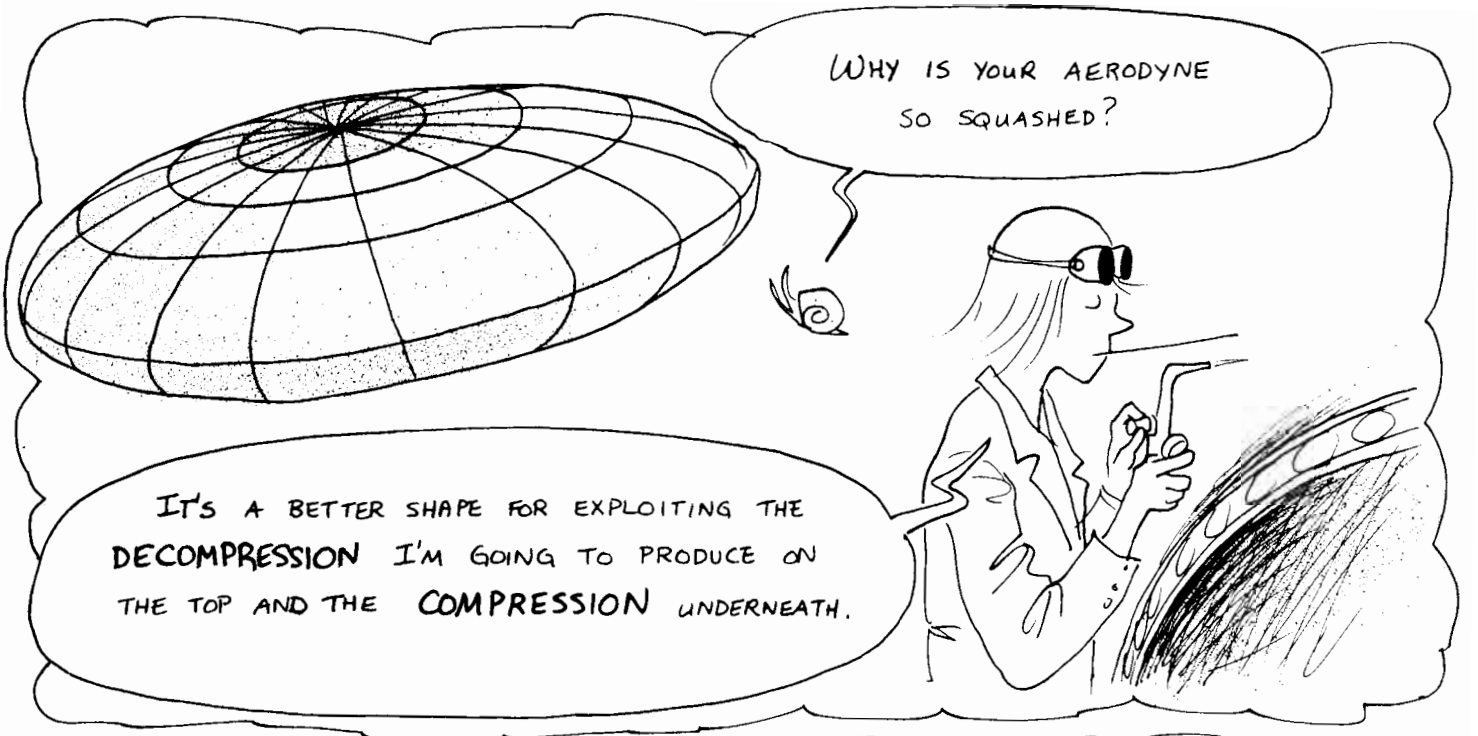
IT'S A THERMAL BLOCKAGE.

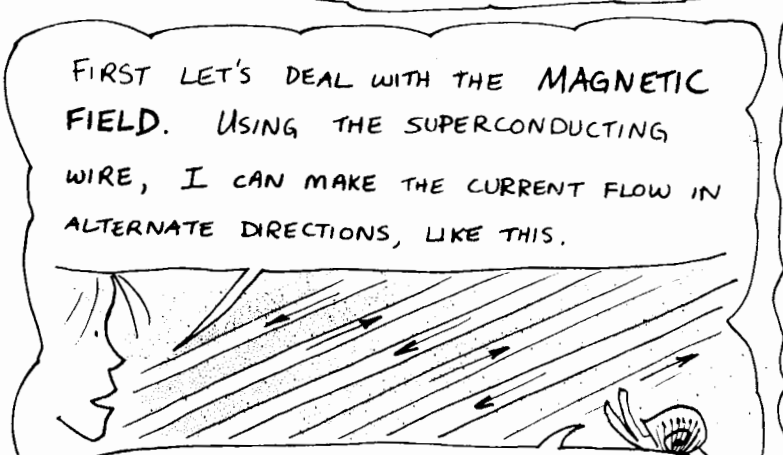
THAT'S NOT SO CLEAR. IT ALL DEPENDS ON THE ELECTRICAL CONDUCTIVITY OF THE AIR (AND THE VARIOUS WAYS OF AFFECTING IT). IF IT'S HIGH ENOUGH(*) THEN THE PRODUCTION OF HEAT WILL STAY MODERATE, AND THERE WON'T BE ANY BLOCKAGE.

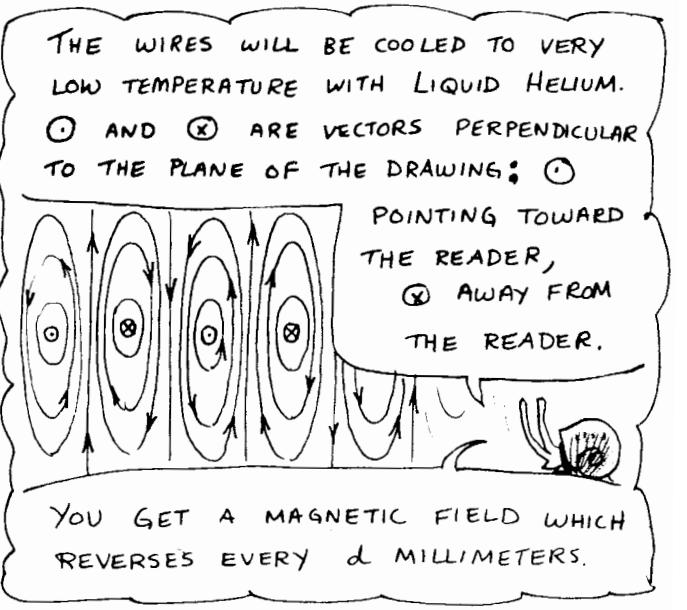
(*) SEE APPENDIX E (PAGE 71)

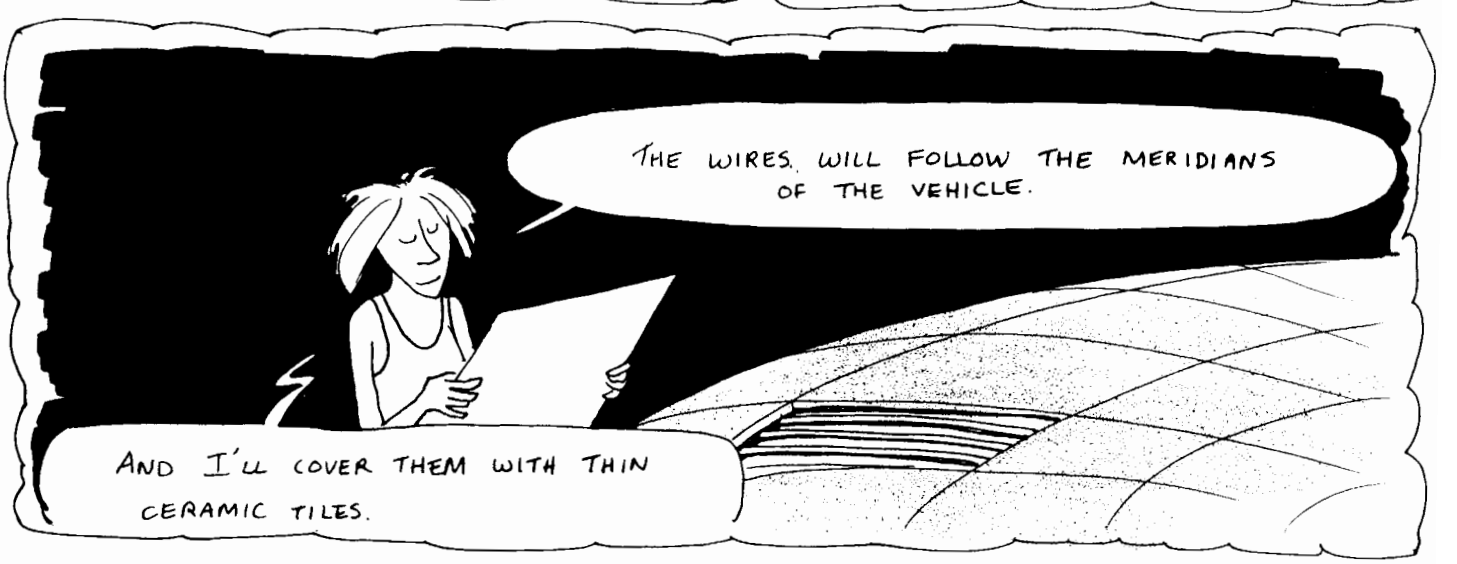

OH, LOOK AT ARCHIE....
HE'S GONE TO SLEEP AGAIN.
WHAT A SURPRISE....
WHAT DO YOU MAKE OF ALL THAT?
H'INASMUCH AS THESE 'ERE MHD H'AERODYNE WOTSITS CORRESPOND TO TECHNOLOGY WOT MIGHT 'APPEN IN THE NEX' CENCHERY - IT'S QUESTIONABLE WEVVER IT'S WORF THE BLEEDIN' CANDLE, INNIT?
BUT THERE MIGHT BE SOME INTEREST FOR BASIC SCIENCE?
YUR, SURE, BASIC SCIENCE....
HEAVENS... WHAT A DAY!
SLEEP, PRINCIPLE INVESTIGATOR OF MY HEART.

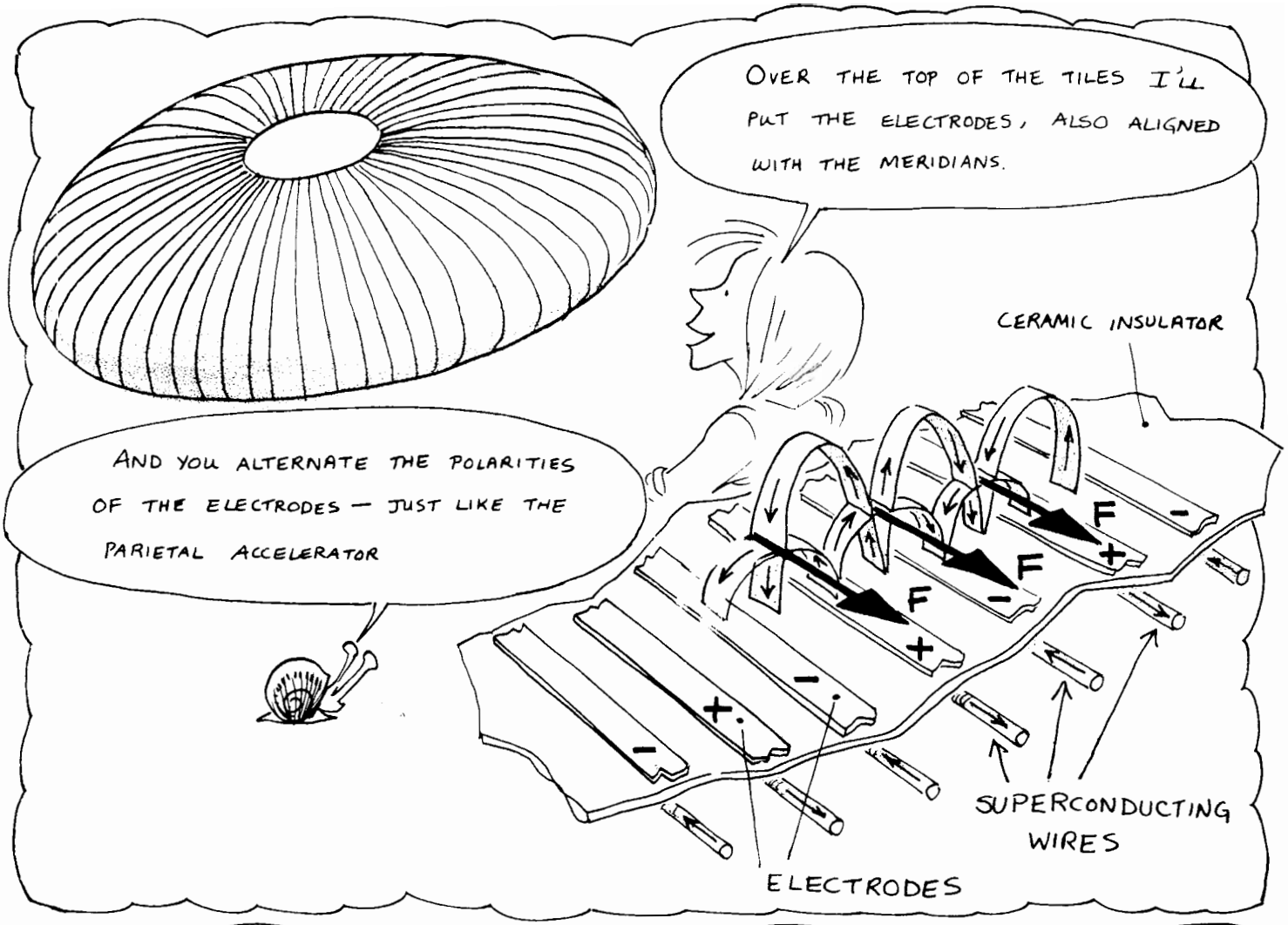
ARCHiBALD'S DREAM

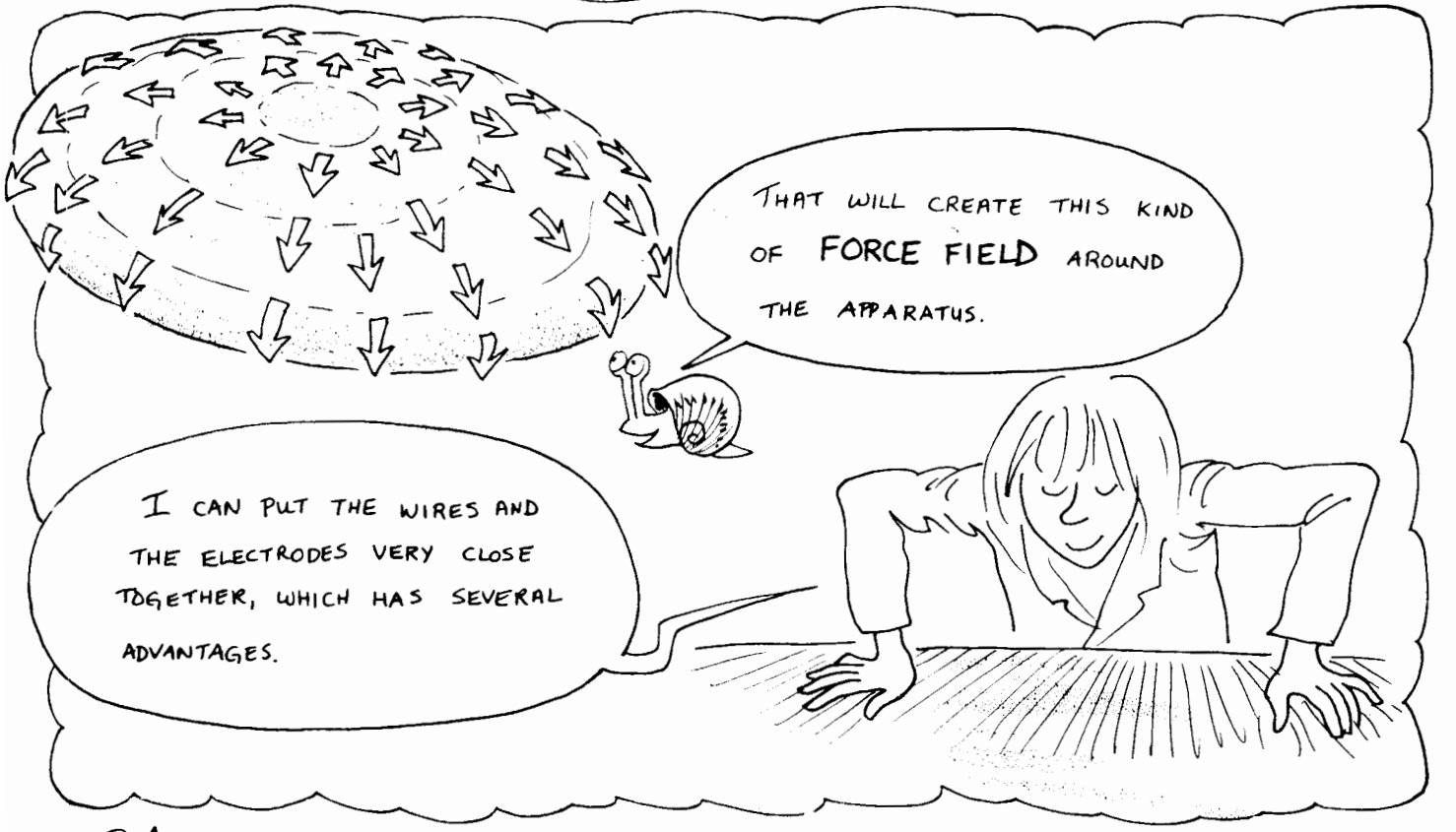

WHY IS YOUR AERODYNE SO SQUASHED?
IT'S A BETTER SHAPE FOR EXPLOITING THE DECOMPRESSION I'M GOING TO PRODUCE ON THE TOP AND THE COMPRESSION UNDERNEATH.


FIRST LET'S DEAL WITH THE MAGNETIC FIELD. USING THE SUPERCONDUCTING WIRE, I CAN MAKE THE CURRENT FLOW IN ALTERNATE DIRECTIONS, LIKE THIS.
IN THESE PARALLEL WIRES, THE CURRENT REVERSES FROM ONE TO THE NEXT.


THE WIRES WILL BE COOLED TO VERY LOW TEMPERATURE WITH LIQUID HELIUM. ⊙ AND ⊗ ARE VECTORS PERPENDICULAR TO THE PLANE OF THE DRAWING: ⊙ POINTING TOWARD THE READER, ⊗ AWAY FROM THE READER.
YOU GET A MAGNETIC FIELD WHICH REVERSES EVERY d MILLIMETERS.


THE WIRES WILL FOLLOW THE MERIDIANS OF THE VEHICLE.
AND I'LL COVER THEM WITH THIN CERAMIC TILES.


OVER THE TOP OF THE TILES I'LL PUT THE ELECTRODES, ALSO ALIGNED WITH THE MERIDIANS.
CERAMIC INSULATOR
AND YOU ALTERNATE THE POLARITIES OF THE ELECTRODES — JUST LIKE THE PARIETAL ACCELERATOR
F
F
F
SUPERCONDUCTING WIRES
ELECTRODES

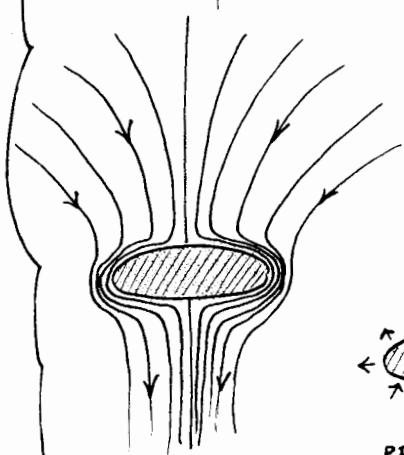

THAT WILL CREATE THIS KIND OF FORCE FIELD AROUND THE APPARATUS.
I CAN PUT THE WIRES AND THE ELECTRODES VERY CLOSE TOGETHER, WHICH HAS SEVERAL ADVANTAGES.

FIRST, IT KEEPS DOWN THE VOLTAGE I NEED TO APPLY TO THE ELECTRODES.

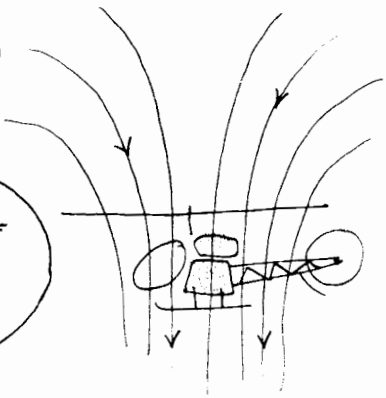
SECOND, IT KEEPS DOWN THE VOLUME IN WHICH THE MAGNETIC FIELD IS CREATED. IN PRACTICAL TERMS, THAT'S THE AREA OF THE SURFACE OF THE MACHINE, MULTIPLIED BY THE SPACING BETWEEN THE WIRES.

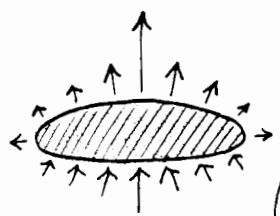
THIRD, THE ACTION TAKES PLACE IN A THIN LAYER, CONCENTRATING THE IONIZATION, THE FORCE.

AND HERE'S THE GASEOUS FLOW THAT RESULTS.

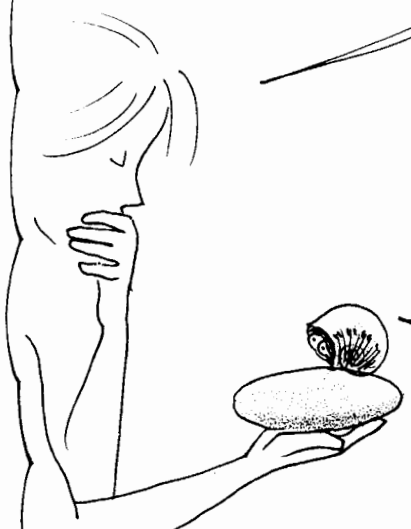


IT'S LIKE A SORT OF ELECTROMAGNETIC HELICOPTER.





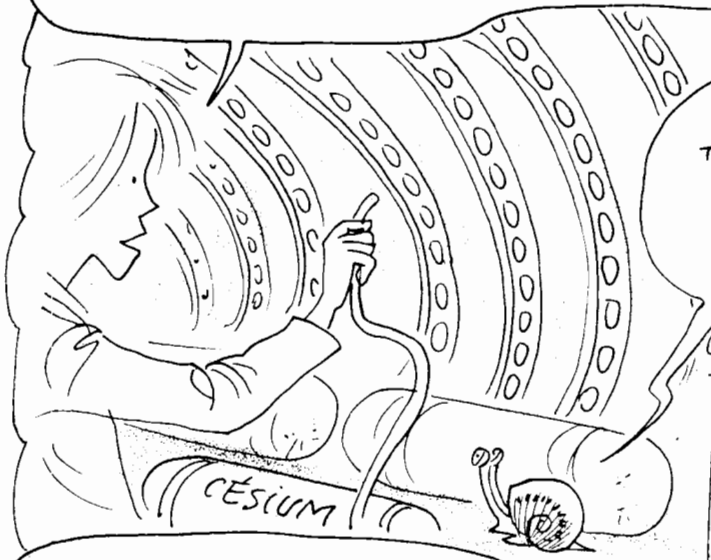
IT JUST REMAINS TO PRODUCE ENOUGH IONIZATION, THAT IS, ENOUGH **FREE ELECTRONS** IN THE LAYER OF GAS.



IF YOU PUT THE ELECTRODES A MILLIMETER APART AND USE A THOUSAND VOLTS, THAT SHOULD BE ENOUGH TO STRIP ELECTRONS FROM THE ATOMS, FREEING THEM FOR A CURRENT TO PASS.

THE iONiZATiON PROBLEM

THE COMPONENT OF THE AIR THAT PROVIDES FREE ELECTRONS ISN'T OXYGEN OR NITROGEN, BUT NITROUS OXIDE (NO). BUT THE SIMPLEST SOLUTION IS TO ENRICH THE AIR WITH A SUBSTANCE THAT GIVES OFF PLENTY OF FREE ELECTRONS, SUCH AS CESIUM OR SODIUM.



SO WE BORE **PORES** THROUGH THE CERAMIC COVERING, AND EMIT SMALL QUANTITIES OF CESIUM VAPOR THROUGH THEM DURING FLIGHT.

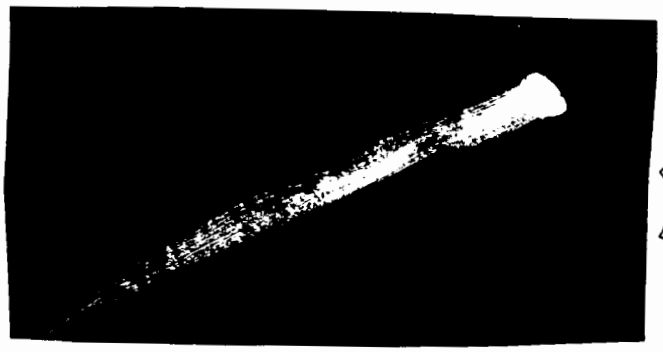
ON BOARD, ARCHIE'S GOT A GENERATOR PRODUCING A VERY HIGH FREQUENCY ALTERNATING ELECTRIC FIELD IN THE SURROUNDING AIR (THREE THOUSAND MEGAHERTZ).

THESE MICROWAVES ARE RAPIDLY ABSORBED BY THE LAYER OF AIR SURROUNDING THE MACHINE AND ALSO PRODUCE FREE ELECTRONS.


LAYER OF PLASMA
PATH OF A MOLECULE OF GAS
IONIZATION
DEIONIZATION ACCOMPANIED BY LIGHT EMISSION
RIGHT, I RECKON THAT'S THE LOT. AN INTERNAL TELEVISION CIRCUIT, USING MICROCAMERAS DISTRIBUTED OVER THE SURFACE, WILL GIVE AS GOOD A VIEW OF THE OUTSIDE.
T MINUS TEN AND COUNTING...
WHAT'S THAT GADGET?
IONIZATION!
IT'S LUMINOUS... REDDISH....
STRIKE ME PINK! LENNY AND HIS FRIEND, OVER THERE....
THEY'D BETTER LOOK OUT FOR THE MICROWAVES!
WE'D BETTER MOVE AS FAST AS WE CAN!
RAISE THE LANDING-GEAR!


CRAZY... IT FLIES JUST LIKE A HELICOPTER.
!?
SOPHIE!
EXCEPT THAT INSTEAD OF CHANGING THE ANGLE OF THE ROTOR BLADES, YOU ALTER THE CURRENTS.
LOOK AT THESE TWO! WHAT'S HAPPENED TO THEM? THEY LOOK LIKE THEY'VE SEEN THE DEVIL.
IT'S WEIRD. THEY'RE TOTALLY ZONKED OUT...

THE **MHD AERODYNE** CONTINUES ON ITS WAY, LEAVING BEHIND A LONG, BRIGHT TRAIL OF CESIUM VAPOR.



PILE ON THE COALS!

THE POWER INCREASES, AND THE MACHINE ASSUMES THE ASPECT OF A SHOOTING STAR....

OH GOSH, WOW, GOLLY! WE'RE GOING AT LEAST FOUR OR FIVE TIMES FASTER THAN SOUND!

HEY, ARCHIE... SINCE WE'RE CONTROLLING THE GAS FLOW COMPLETELY, WE'RE FLYING WITHOUT ANY TURBULENCE OR SHOCKWAVES, RIGHT?

I GUESS,

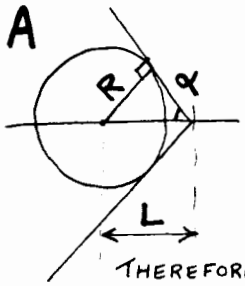
ERGO... NO NOISE.

FIRST THERE'S THE **SOUND BARRIER**... THEN THE **HEAT BARRIER**... AND NOW, I GET THE FEELING WE'VE BROKEN...

THE END

SCIENTIFIC APPENDIXES

A



DURING A TIME t, AN EMITTED WAVE PROPAGATES RADIALLY TO A DISTANCE $R = V_s t$, WHILE THE OBJECT MOVES $L = Vt$.

THEREFORE $\frac{V}{V_s} = \frac{L}{R}$ $\quad \sin\alpha = \frac{V_s}{V} = \frac{R}{L}$

B

IT IS POSSIBLE TO ACT ON THE WAVE SYSTEM IF THE ENERGY RECEIVED BY THE VOLUME ELEMENT **JBL** (WORK DONE BY THE LAPLACE FORCE ALONG THE INTERACTION LENGTH) IS GREATER THAN THE KINETIC ENERGY $\frac{1}{2}\rho V^2$. IN SALT WATER ELECTROLYSIS LIMITS J TO 1 A/CM² (10^4 A/M²). SUPPOSE V = 8 CM/SEC.

ASSUME THE CYLINDER GOES 8MM (8×10^{-3} M), WITH AN INTERACTION LENGTH EQUAL TO THE SIZE OF THE ELECTRODE: 2×10^{-3} M; AND $\rho = 10^3$ KG/M³. IF B = 1 TESLA (10,000 GAUSS) THE INTERACTION PARAMETER IS $S = \frac{2JBL}{V^2} = 10$. THE BOW WAVE IS ANNIHILATED....

C

THE BOAT HAS A THRUST OF 1 GRAM. OR 10^{-3} KG OR 10^{-2} NEWTONS. IT TRAVELS AT 0.1 M/SEC, CORRESPONDING TO A POWER OF 10^{-3} WATTS. THE GENERATOR SUPPLIES 25 VOLTS, 20 AMPERES, THAT IS, 500 WATTS. THE EFFICIENCY IS THUS $\eta = \frac{10^{-3}}{500} = 2 \times 10^{-6}$.

FLUID PASSES THROUGH THE ACCELERATOR IN TIME t. SO THE PROPULSIVE POWER IS $\frac{JBL}{t}$.

BUT $\frac{L}{t}$ IS THE SPEED V. MOREOVER, THE POWER DISSIPATED BY THE JOULE EFFECT IS J^2/σ, WHERE σ IS THE ELECTRICAL CONDUCTIVITY.

SO THE EFFICIENCY IS $\eta = \frac{JBV}{JBV + J^2/\sigma}$

WITH σ = 10 MHOS/M
B = 25 TESLAS
V = 20 M/SEC
$J = 10^4$ A/M²

WE GET $\eta = 0.33$

THE EFFICIENCY INCREASES WITH V.

D

THE EXCESS PRESSURE AT THE STATIONARY POINT WILL BE, IN ALL, $\frac{1}{2}\rho V^2$, WHERE ρ IS THE DENSITY OF THE AIR (1.3 KG/M³) AND V IS THE SPEED OF THE OBJECT. FOR A FRONTAL AREA OF 1 M², THE POWER P LOST IN THE WAVE TRAIN WILL BE $\frac{1}{2}\rho V^3$.

IF V = 600 M/S $\quad P$ = 200 MW
IF V = 1500 M/S $\quad P$ = 2000 MW

E

THE POWER ASSOCIATED WITH MHD ACCELERATION IS **JBV**. WITH $J = 10^4$ A/M², B = 4 TESLAS, V = 1000 M/SEC, WE HAVE JBV = 40 MW/M³. IF THE ELECTRICAL CONDUCTIVITY OF THE AIR (AWAY FROM EQUILIBRIUM) REACHES 10 MHOS/M, THAT OF SALT WATER, THEN THE HEAT J^2/σ PRODUCED BY THE JOULE EFFECT, CORRESPONDS TO A POWER OF 10 MW/M³. IT'S ATTAINABLE. IT WOULD BE BEST TO WORK WITH B LARGE (20 TESLAS) AND TO INCREASE ARTIFICIALLY THE CONDUCTIVITY σ (BY EMITTING ALKALI THROUGH A POROUS WALL OR VIA THE ACTION OF MICROWAVES).