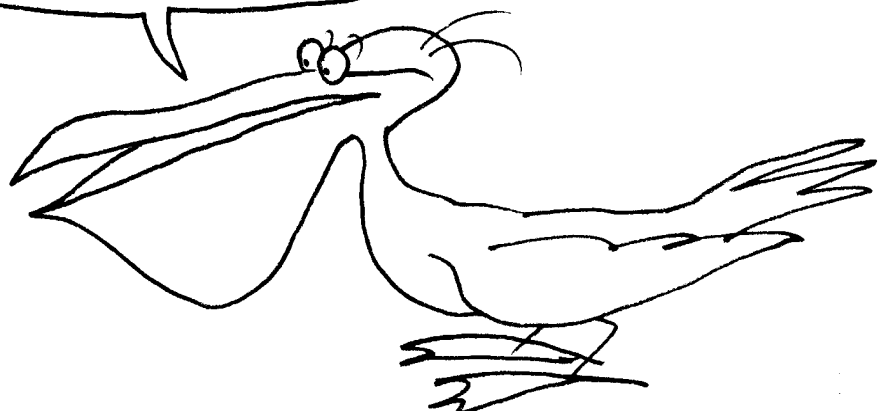


The Adventures of  
Archibald Higgins  
(Anselme Lanturlu)

# THE SILENCE BARRIER

Jean-Pierre  
Petit

Now remember don't  
make any waves!



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.



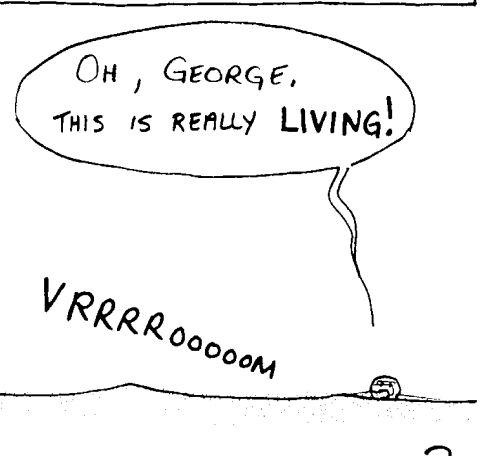
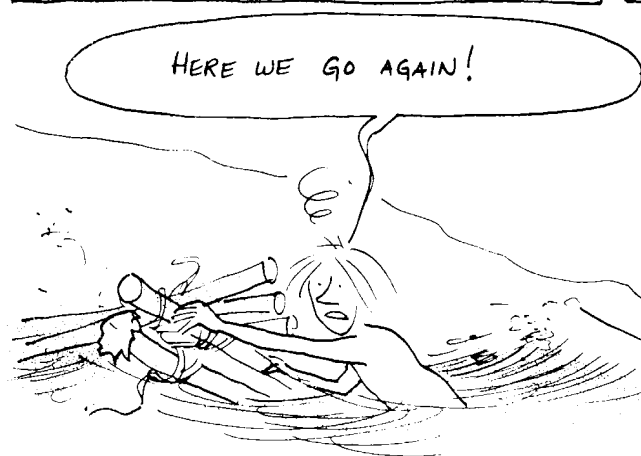
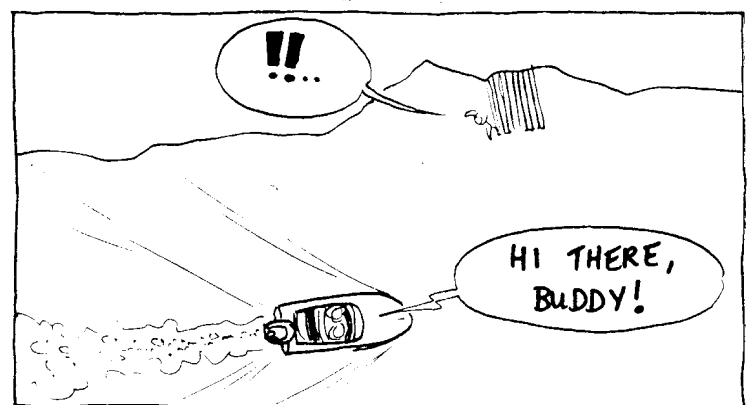
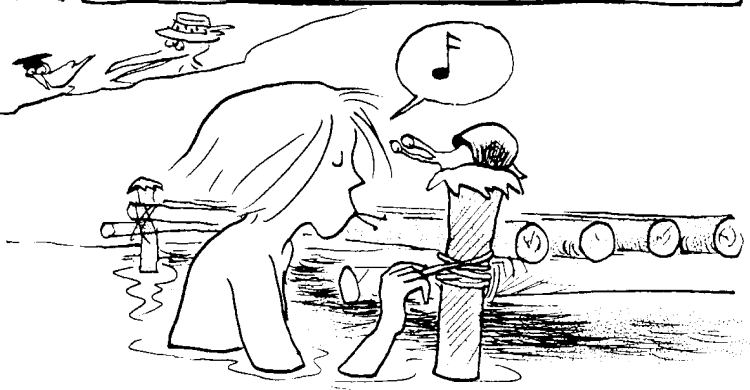
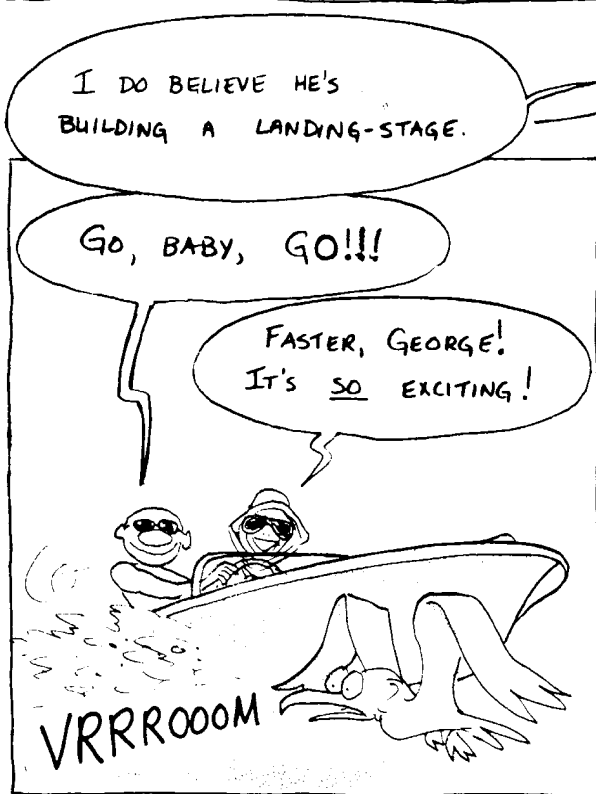
Jean-Pierre Petit intends to create numerous other works which will be accessible to a larger audience. Even illiterate people will be able to read them because the written parts will “speak” when the readers click on them. Thus it will be possible to use these works to support literacy schemes. Other 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.

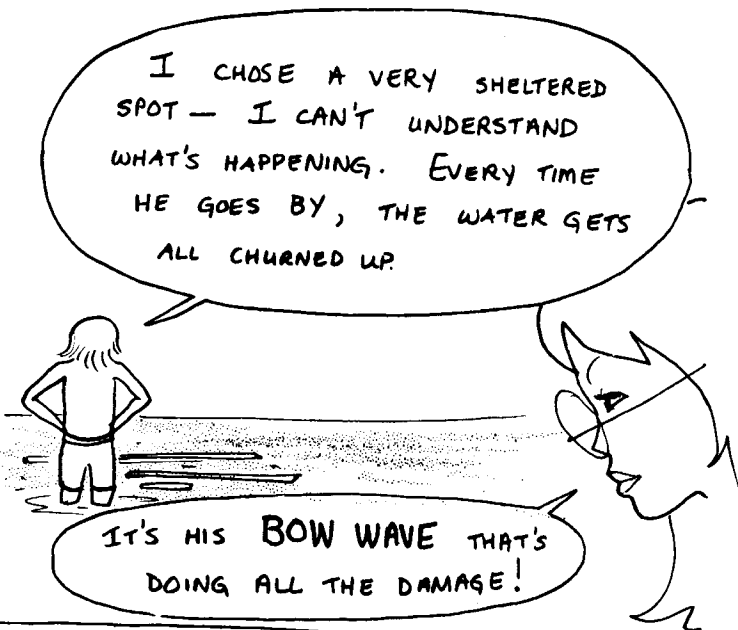
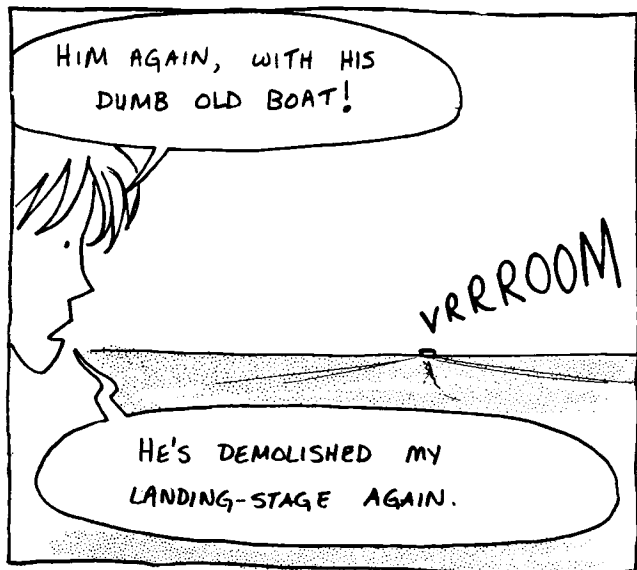
Jean-Pierre Petit was born in 1937. He made his career in French research. He worked as a plasma physicist, he directed a computer science centre, he has created softwares, he has published hundreds of articles in scientific magazines, dealing with subjects ranging from fluid mechanics to theoretical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



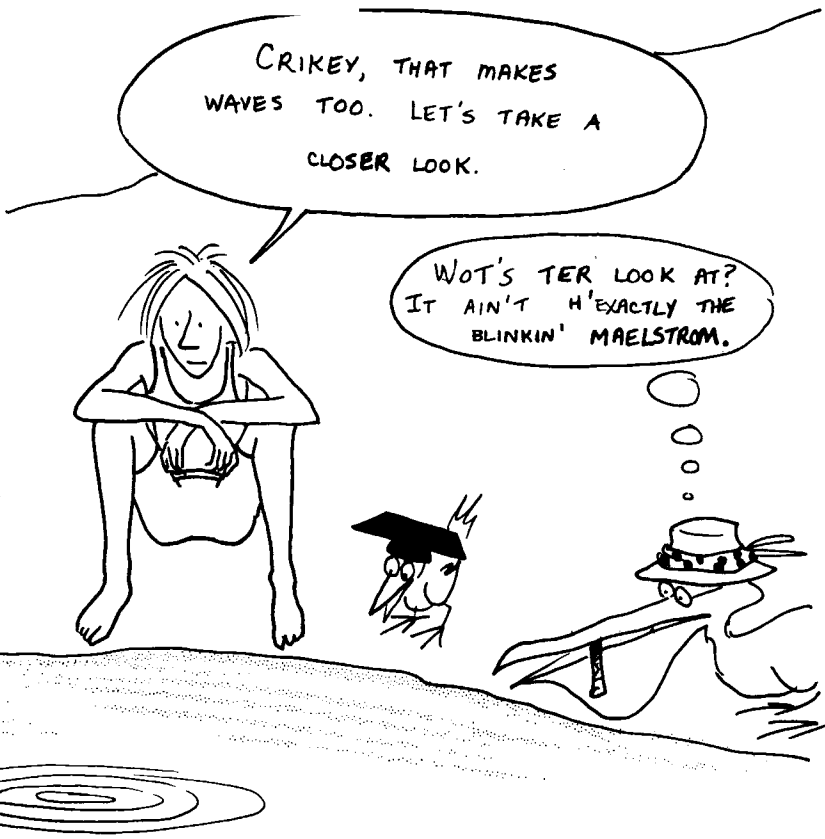
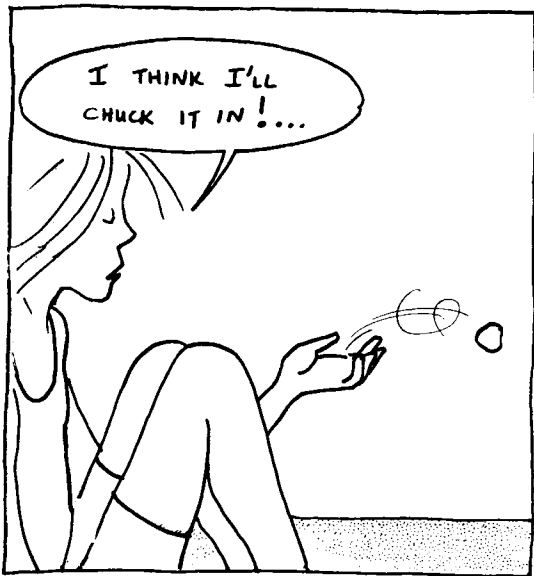


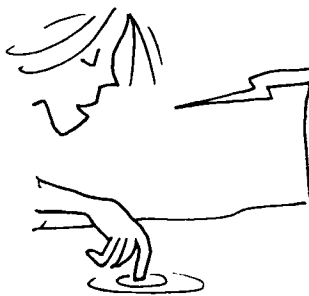
OH, THAT'S TEWWIBLE! THE MAN MUST BE A WAVING LUNATIC!



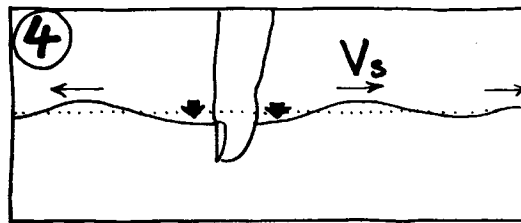
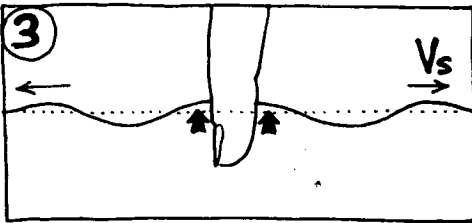
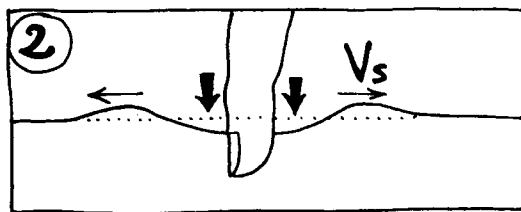
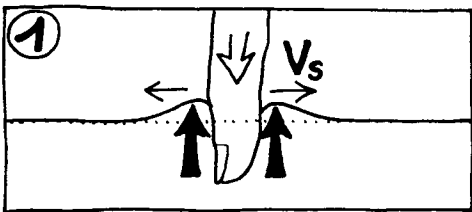
A speech bubble containing the text 'OH, THAT'S TEWWIBLE! THE MAN MUST BE A WAVING LUNATIC!' is shown. To the right of the bubble is a small drawing of a seashell.

# SURFACE WAVES

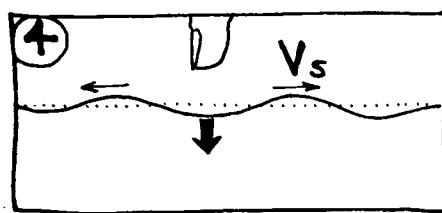
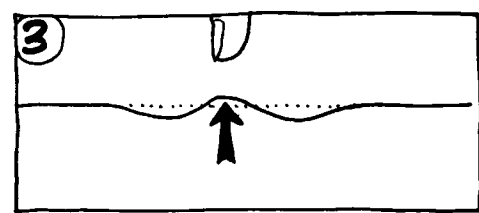
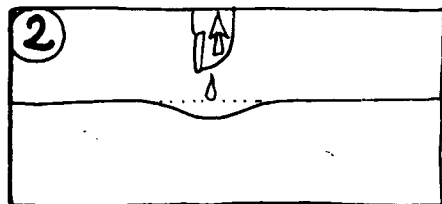
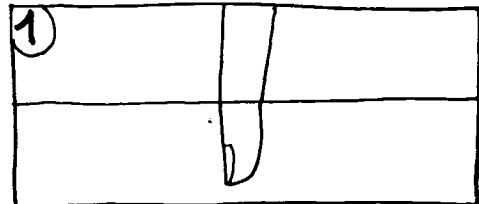




IF I STICK MY FINGER IN SUDDENLY, IT MAKES THE WATER NEARBY RISE TO FORM A SORT OF "SPARE TIRE." THE EXTRA THICKNESS LEADS TO OSCILLATIONS, WHICH ELIMINATE IT, FORMING CONCENTRIC SURFACE WAVES. THESE APPEAR TO TRAVEL AT A CONSTANT SPEED, WHICH I'LL CALL  $V_s$ ; AND AS THEY MOVE, THEY SLOWLY DIE AWAY.

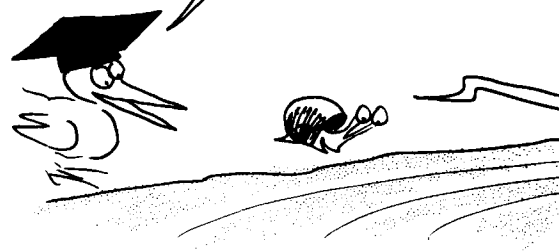


A SIMILAR EFFECT OCCURS IF, INSTEAD OF STICKING YOUR FINGER INTO THE WATER, YOU PULL IT OUT. AS A RESULT, THE LIQUID TENDS TOWARD A FREE PLANAR SURFACE.



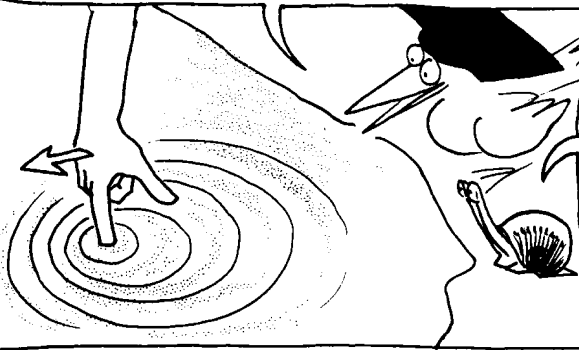
COR! BARFROOM PHYSICS!

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



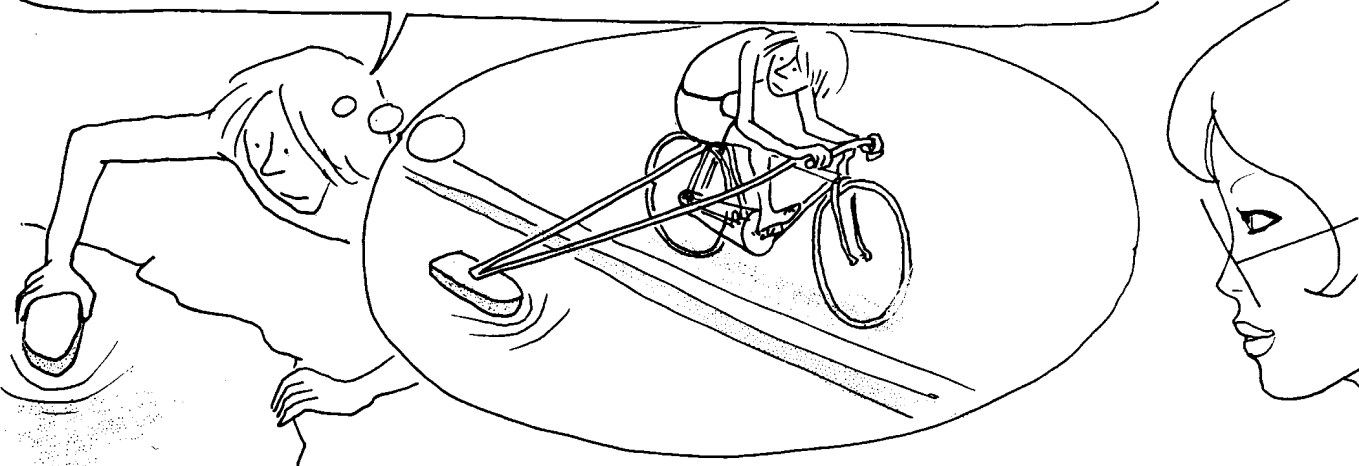
AND SINCE ENERGY IS CONSERVED, THE HEIGHT - OR AMPLITUDE - OF THE WAVES MUST PROGRESSIVELY DECREASE.

IF AN OBJECT MOVES ABOUT IN THE WATER, IT EMITS THIS TYPE OF WAVE, THEREBY ROUGHENING THE SURFACE OF THE WATER.

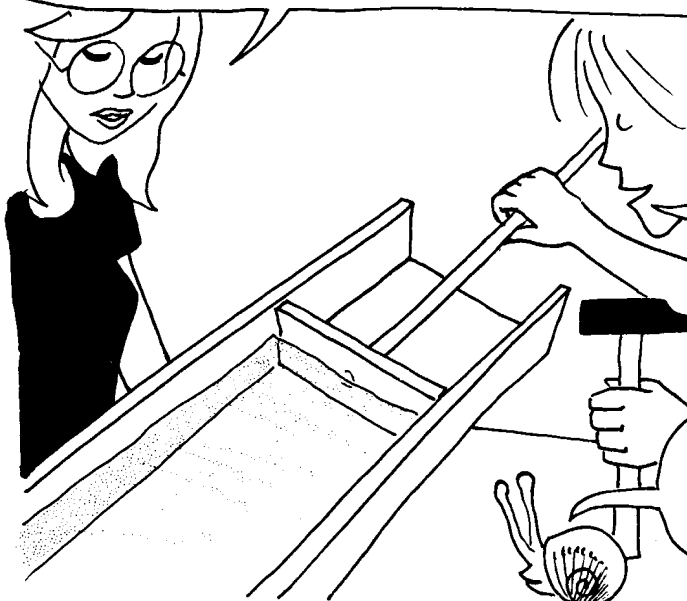


THE WAVES ACT ON THE FLUID. THEY START TO SEPARATE THE MOLECULES UPSTREAM, LETTING THE FLUID THERE MOVE TOWARDS THE OBJECT.

IF I WANT TO TAKE A LOOK AT THAT, I'D BETTER FIND A WAY OF FOLLOWING THE FLUID AS IT MOVES.



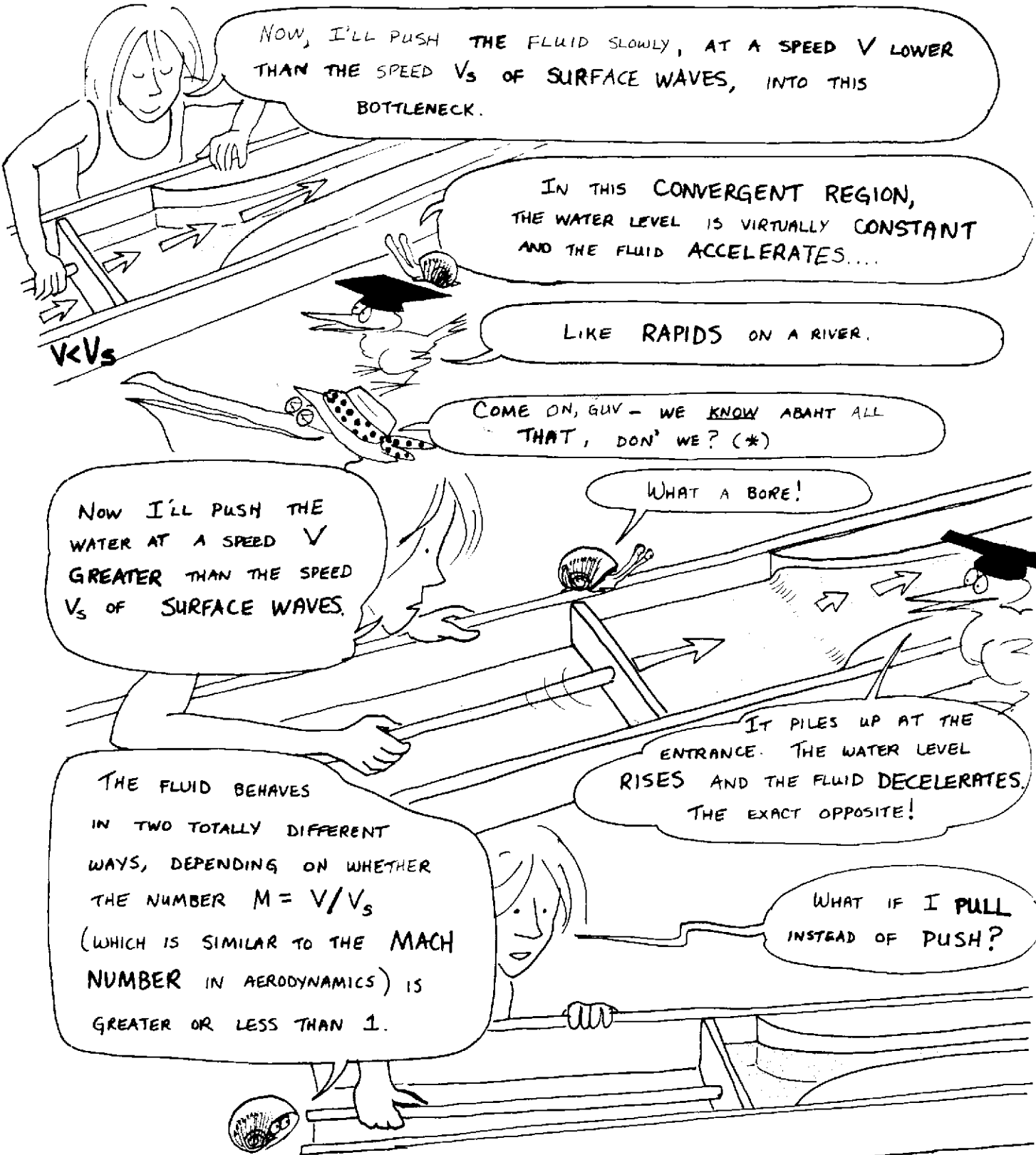
DON'T YOU THINK THAT'S A RATHER COMPLICATED SYSTEM? INSTEAD OF MOVING THE OBJECT, I SUGGEST YOU KEEP IT FIXED AND MOVE THE FLUID.



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



NOW, I'LL PUSH THE FLUID SLOWLY, AT A SPEED  $V$  LOWER THAN THE SPEED  $V_s$  OF SURFACE WAVES, INTO THIS BOTTLENECK.

IN THIS CONVERGENT REGION, THE WATER LEVEL IS VIRTUALLY CONSTANT AND THE FLUID ACCELERATES...

LIKE RAPIDS ON A RIVER.

COME ON, GUY - WE KNOW ABOUT ALL THAT, DON' WE? (\*)

NOW I'LL PUSH THE WATER AT A SPEED  $V$  GREATER THAN THE SPEED  $V_s$  OF SURFACE WAVES.

WHAT A BORE!

IT PILES UP AT THE ENTRANCE. THE WATER LEVEL RISES AND THE FLUID DECELERATES. THE EXACT OPPOSITE!

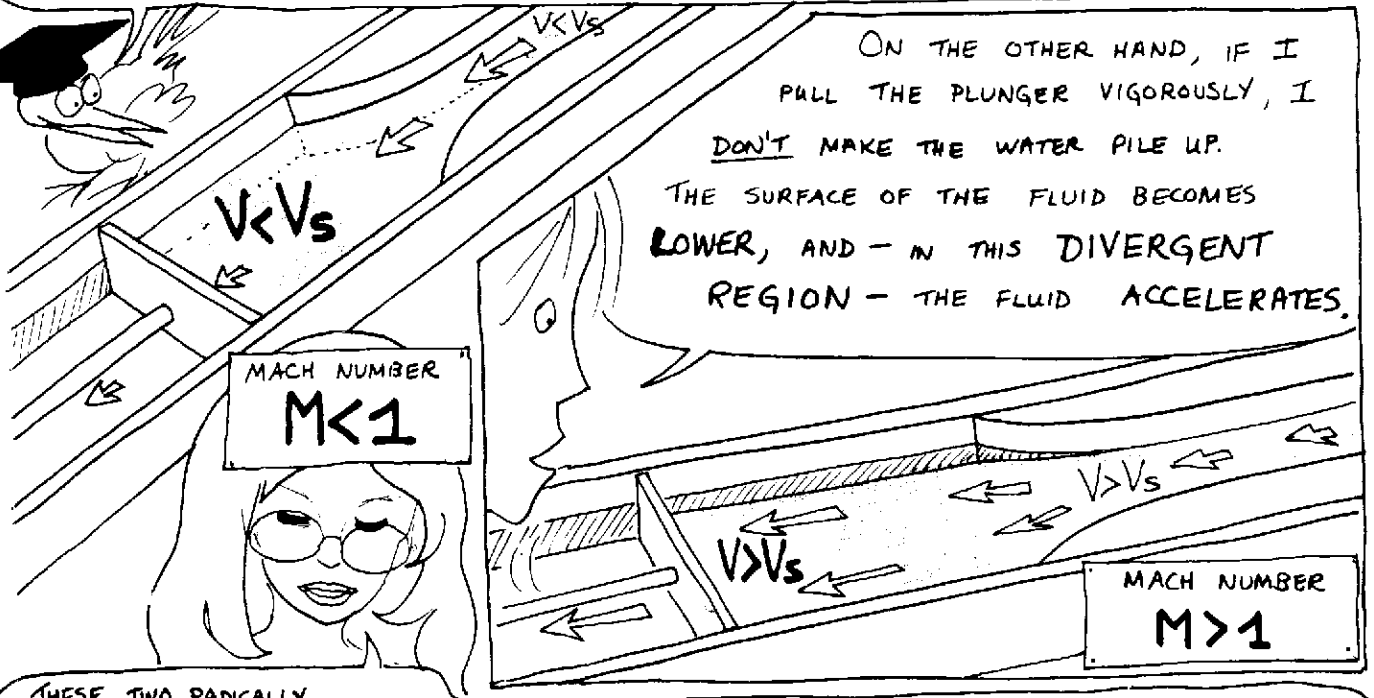
THE FLUID BEHAVES IN TWO TOTALLY DIFFERENT WAYS, DEPENDING ON WHETHER THE NUMBER  $M = V/V_s$  (WHICH IS SIMILAR TO THE MACH NUMBER IN AERODYNAMICS) IS GREATER OR LESS THAN 1.

WHAT IF I PULL INSTEAD OF PUSH?

(\*) SEE FLIGHT OF FANCY, SAME SERIES.

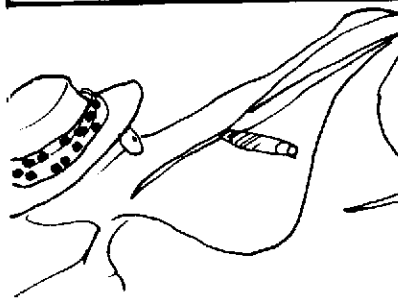
IF YOU PULL GENTLY AND THE SPEED  $V$  OF THE FLUID ALWAYS STAYS LESS THAN THE SPEED  $V_s$  OF SURFACE WAVES, THEN THE WATER DECELERATES IN THIS DIVERGENT REGION, AND THE HEIGHT OF THE WATER REMAINS VIRTUALLY CONSTANT.

ON THE OTHER HAND, IF I PULL THE PLUNGER VIGOROUSLY, I DON'T MAKE THE WATER PILE UP. THE SURFACE OF THE FLUID BECOMES LOWER, AND - IN THIS DIVERGENT REGION - THE FLUID ACCELERATES.



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: THE LEVEL:	ACCELERATES STAYS CONSTANT	DECELERATES RISES
IN A DIVERGENT REGION THE FLUID: THE LEVEL:	DECELERATES STAYS CONSTANT	ACCELERATES DROPS



LEMME SEE... THE MORE YER GOES LESS QUICKLY, THE LESS THE SPEED GETS BIGGER... AT LEAST, MORE OR LESS... OR IS IT THE UVER WAY ROUND?

HiHiHi...



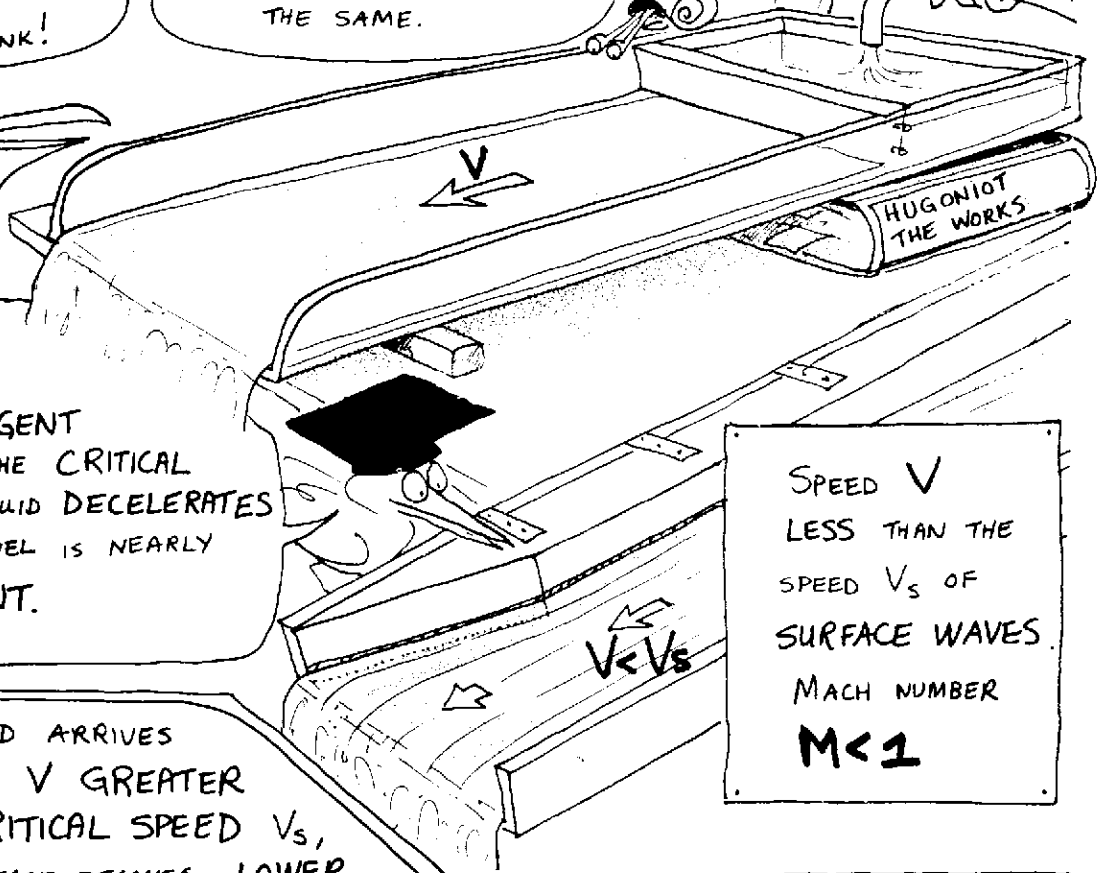


PUFFFFF! ALL THAT WATER'S TOO HEAVY FOR ME TO KEEP SHOVING IT AROUND WITH A PLUNGER. THERE'S GOT TO BE A BETTER WAY...

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!

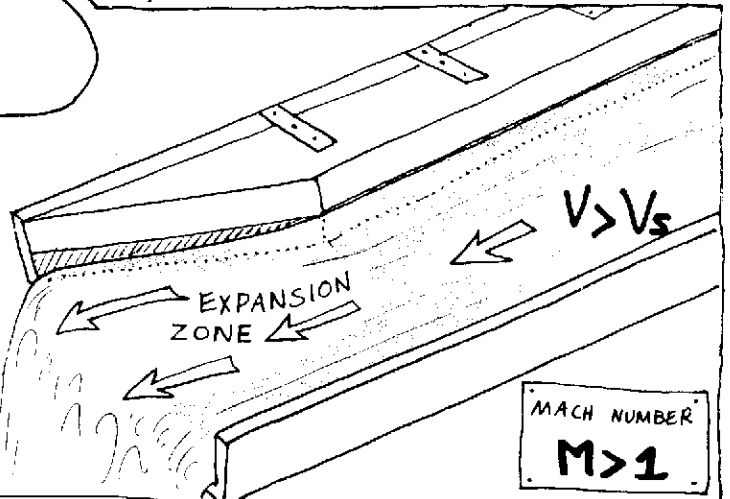
NO, THE RESULT'S EXACTLY  
THE SAME.



BACK TO THE  
FLOW IN A DIVERGENT  
REGION. BELOW THE CRITICAL  
SPEED  $V_s$ , THE FLUID DECELERATES  
AND THE WATER LEVEL IS NEARLY  
CONSTANT.

SPEED  $V$   
LESS THAN THE  
SPEED  $V_s$  OF  
SURFACE WAVES.  
MACH NUMBER  
 $M < 1$

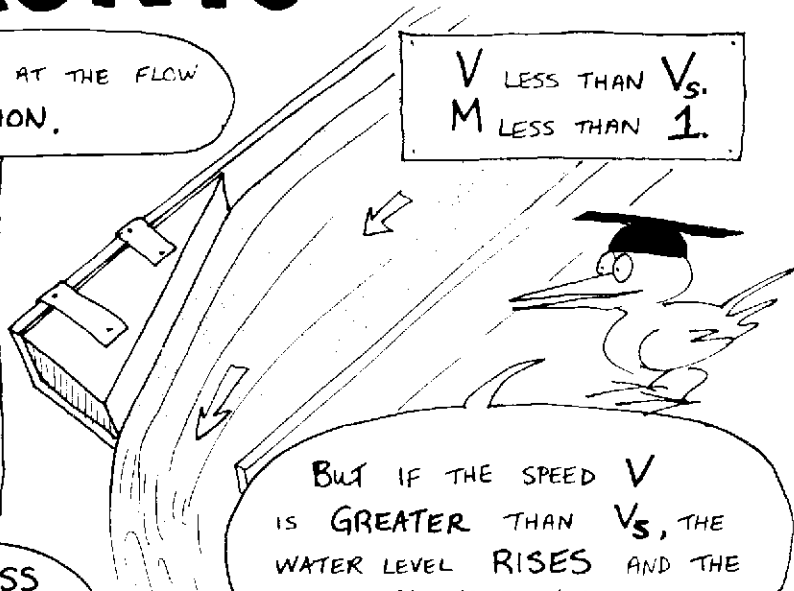
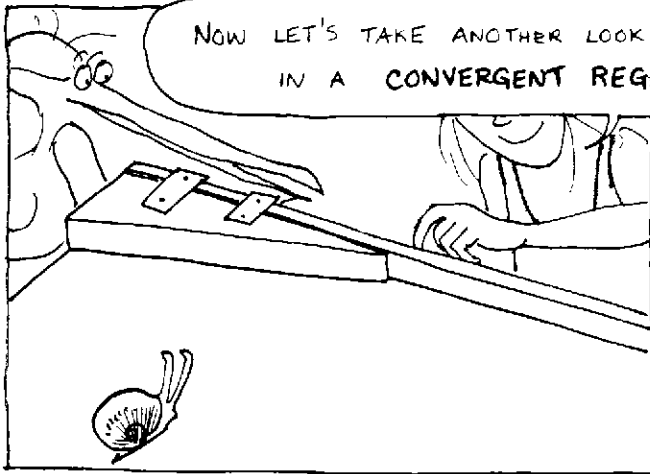
IF THE FLUID ARRIVES  
WITH A SPEED  $V$  GREATER  
THAN THE CRITICAL SPEED  $V_s$ ,  
THEN THE SURFACE BECOMES LOWER  
AND THE WATER ACCELERATES.



# WAVE FRONTS

NOW LET'S TAKE ANOTHER LOOK AT THE FLOW IN A CONVERGENT REGION.

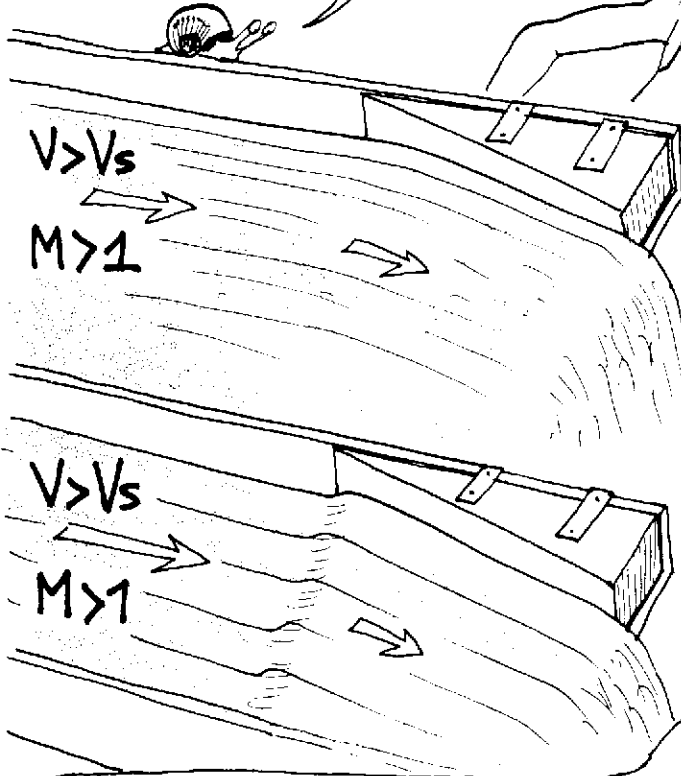
$V$  LESS THAN  $V_s$   
 $M$  LESS THAN 1



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.

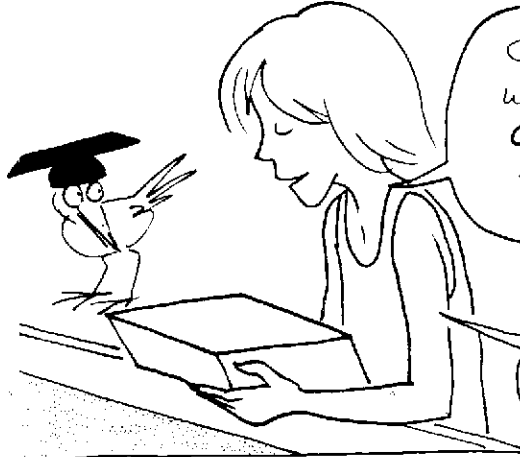
C'MON, ARCHIE—  
 TILT IT A BIT FURVER!



FORMS A BANK, OR A WAVE FRONT. THE WATER SLOWS DOWN AND THE LEVEL RISES.

THE PARAMETERS DESCRIBING THE FLUID CHANGE DRAMATICALLY WHERE IT FORMS A BANK, OR A WAVE FRONT. THE WATER SLOWS DOWN AND THE LEVEL RISES.

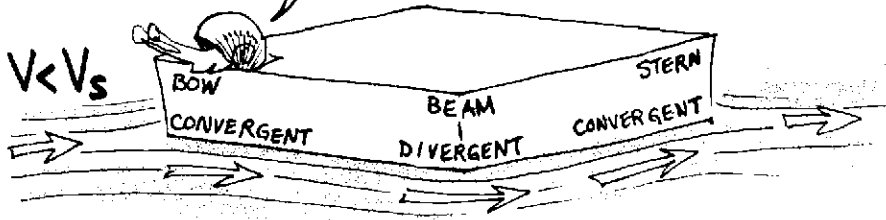
# FLOW ROUND A CONTOUR



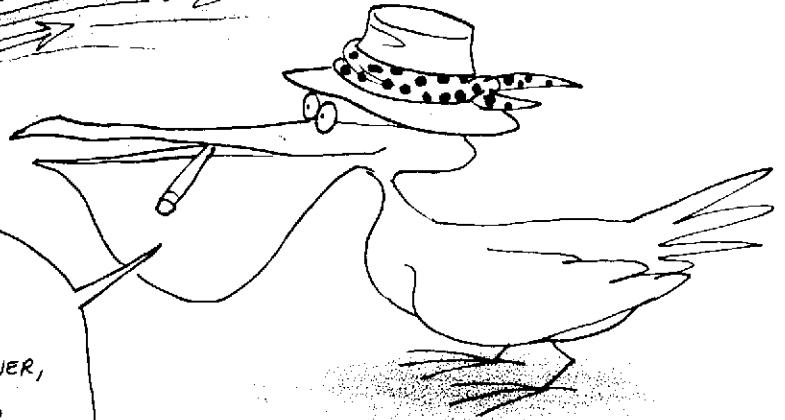
OK, NOW THAT WE'VE SORTED ALL THAT OUT, I WANT TO STUDY THE FLOW OF A FLUID AROUND A CONTOUR. I'LL START IN A REGIME WHERE THE SPEED  $V$  OF THE FLUID IS LESS THAN  $V_s$ .

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

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

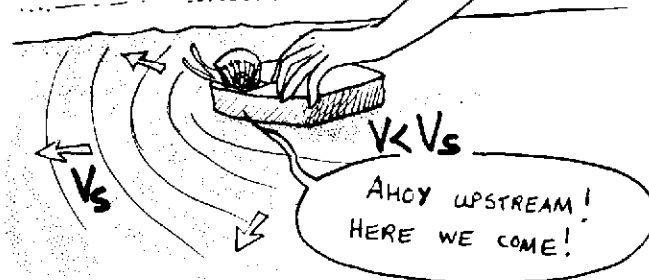


HMMM... YUR, THAT'S WOT IT BOILS DAHN TER. THE SPEED'S FASTEST ARAHND THE SECOND CORNER, THE BEAM. SO THE FLUID SLOWS DAHN UNTIL IT REACHES THE STERN, STAYIN' AT A CONSTANT BLINKIN' LEVEL UNTIL IT GETS BACK TER THE SAME SPEED WOT IT 'AD AT THE BOW.



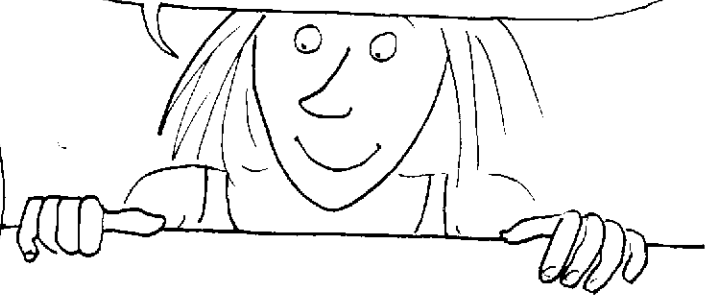


THE SURFACE WAVES, TRAVELING AT A SPEED  $V_s$ , CAN MOVE UPSTREAM AND TRANSMIT ENERGY TO THE FLUID. SO THE FLUID "KNOWS" THAT AN OBJECT IS COMING AND HAS TIME TO GET ITSELF READY TO MEET IT. IT BEGINS TO MOVE APART BEFORE THE OBJECT ARRIVES.

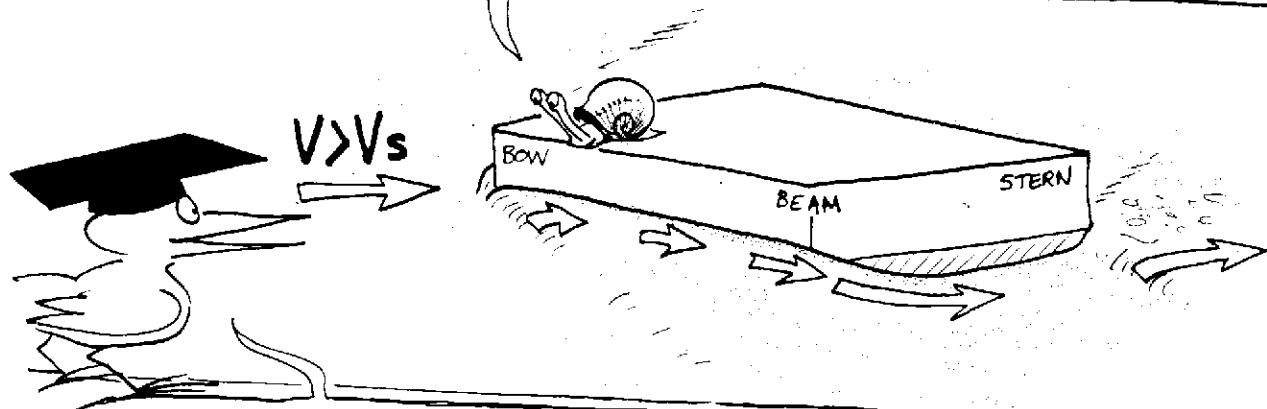


AHOY UPSTREAM!  
HERE WE COME!

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.



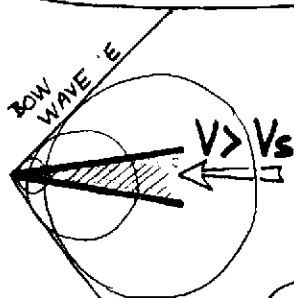
BY HUGONOT'S THEOREM, WE KNOW THAT THE FLUID SLOWS DOWN AT THE BOW, SPEEDS UP AT THE BEAM, AND SLOWS DOWN AGAIN AT THE STERN.



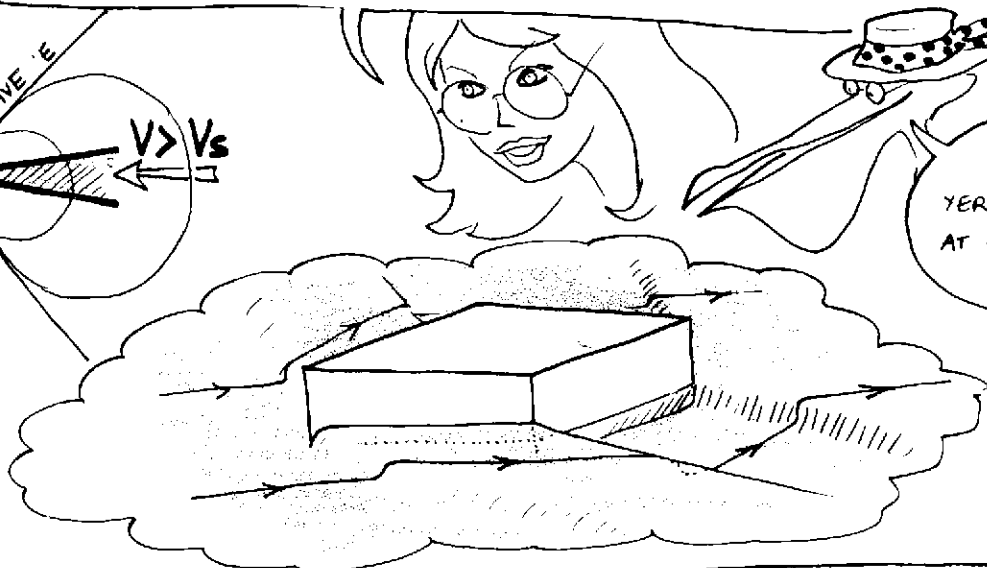
LEVEL WITH THE BOW, THE WATER IS SUDDENLY SLOWED DOWN AND RISES HIGHER THAN THE ORIGINAL WATERLINE. ON PASSING THE SECOND CORNER, THE WATER IS SPEEDED UP AGAIN, EVEN SUPERACCELERATED, THAT IS, INCREASED TO A SPEED GREATER THAN THAT OF "FREE" FLOW. AT THE SAME TIME THE LEVEL DROPS BELOW THE WATERLINE. LEVEL WITH THE STERN, THE SPEED AND LEVEL ARE SUDDENLY READJUSTED TO THEIR ORIGINAL VALUES UPSTREAM.

# THE BOW WAVE

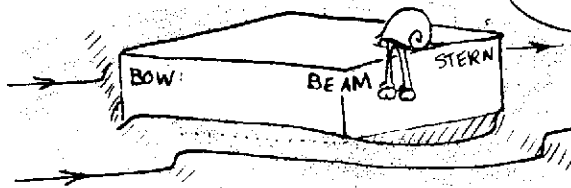
IN THIS REGIME, WHERE THE SPEED  $V$  IS GREATER THAN THE SPEED  $V_s$  OF SURFACE WAVES, WE FIND WAVEFRONTS. THE BOW, FOR EXAMPLE, EMITS SURFACE WAVES THAT TRAVEL TOO SLOWLY TO MOVE UPSTREAM AND THEREFORE PILE UP AGAINST EACH OTHER TO FORM A MOUND OF LIQUID, THE BOW WAVE.



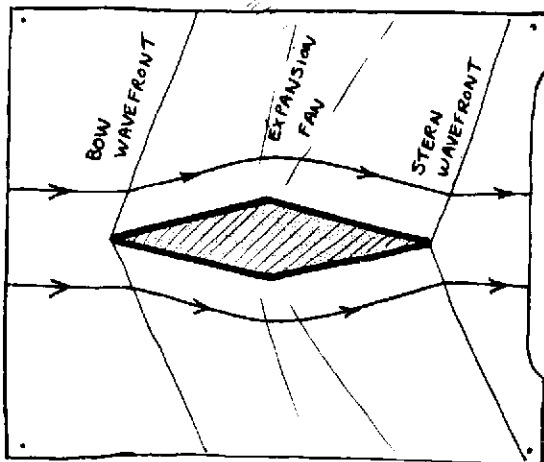
SO THEN YER GETS A BEAM-WAVE AT THE MIDDLE CORNER?



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



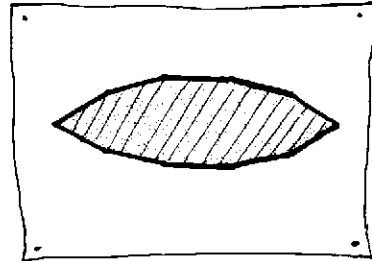
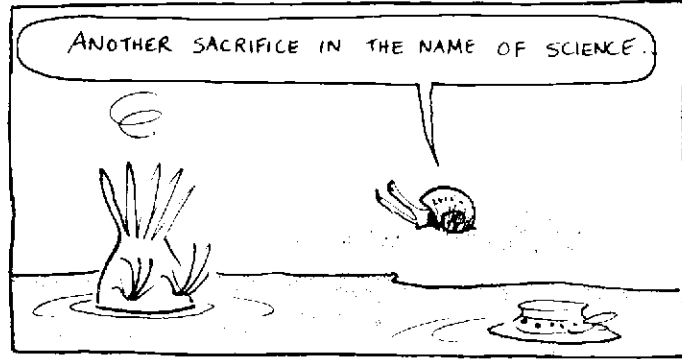
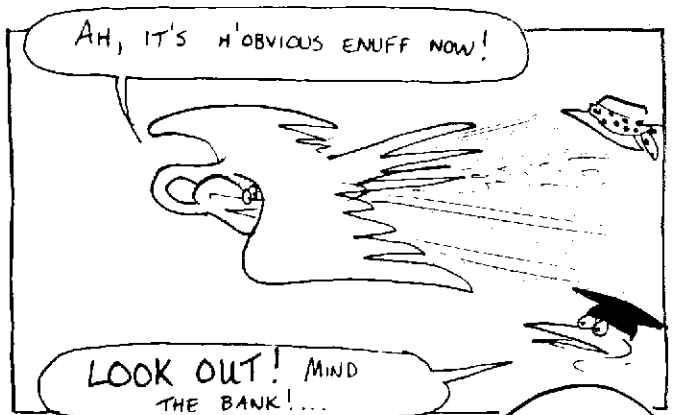
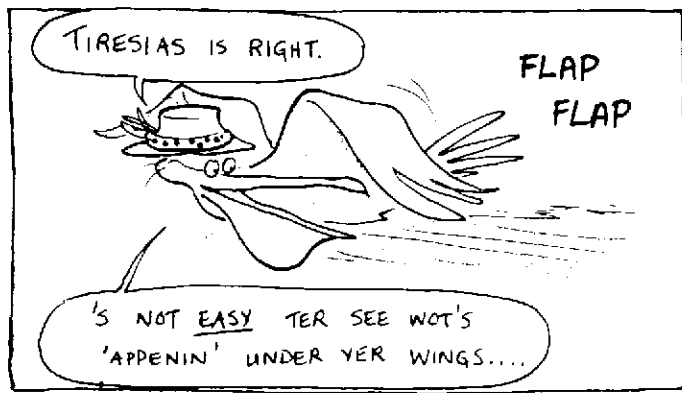
THE ONE TIME I MANAGES TER FINK UP SOMEFINK ORIGINAL, AN' IT'S A FLOP!



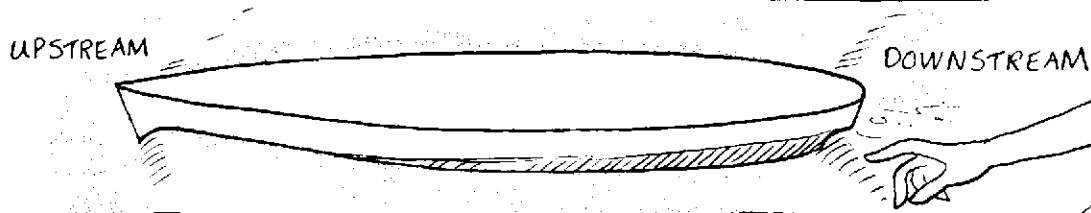
TIRESIAS IS RIGHT, LENNY. THE CHANGES IN SPEED AND LEVEL HAPPEN SUDDENLY AT THE BOW AND STERN, BY MEANS OF WAVEFRONTS. IN CONTRAST, AT THE BEAM, THE SPEED AND LEVEL CHANGE CONTINUOUSLY, ACROSS AN EXPANSION FAN.

OBSERVATION, LENNY. OBSERVATION!



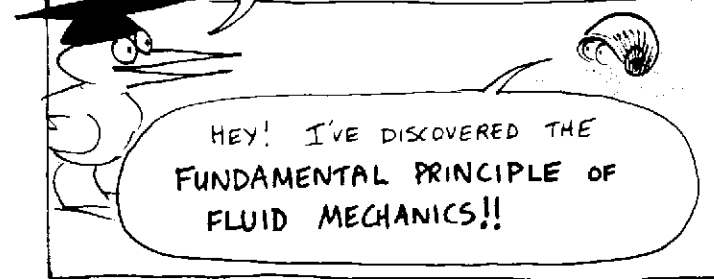


IN A REAL BOAT HULL, THE BEAM IS FORMED BY A SUCCESSION OF VERY MANY TINY CORNERS.



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.



YET AGAIN, TIRESIAS OLD BEAN, YER ASTOUNDS ME. WHAT?



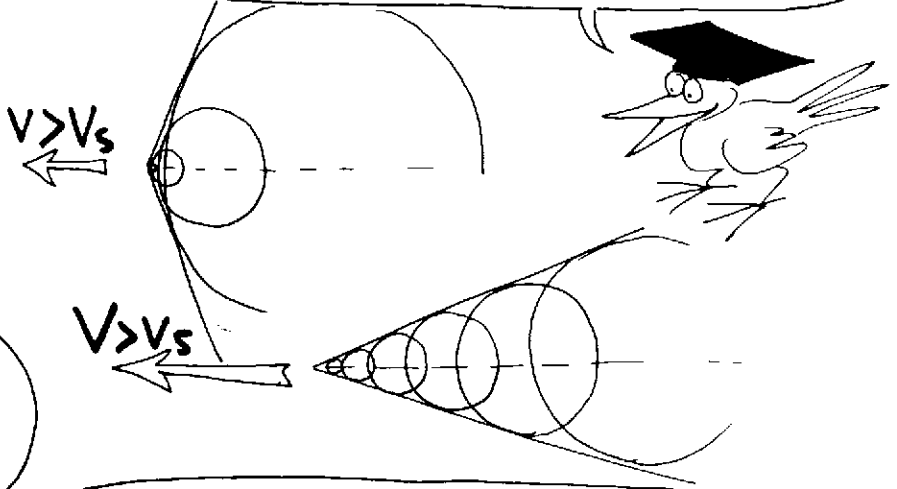
PLEASE LEAVE THE FLUID IN THE STATE IN WHICH YOU WOULD WISH TO FIND IT

# MEASUREMENT OF SPEED

TO UNDERSTAND WHAT'S GOING ON, WHAT I NEED IS SOME WAY TO MEASURE SPEED.

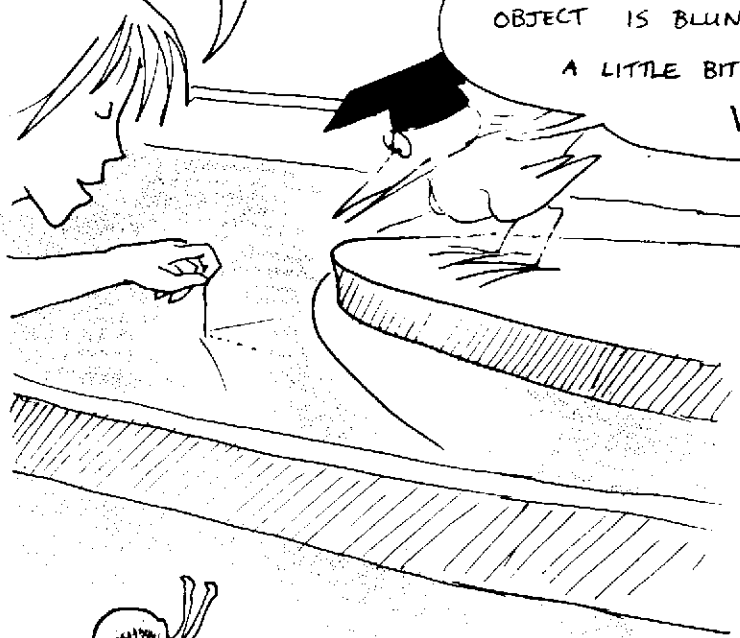


IF YOU PLACE A FINE NEEDLE IN A FLOW WHOSE SPEED  $V$  IS GREATER THAN THE SPEED  $V_s$  OF SURFACE WAVES, THEN THE GREATER THE SPEED, THE CLOSER THE WAVEFRONTS ARE TO THE DIRECTION OF MOTION.



Wow, Max, you're right! That lets me measure the speed  $V$ .(\*)

HAVE YOU NOTICED THAT WHEN THE FRONT OF THE OBJECT IS BLUNT, THEN THE WAVEFRONT IS SET UP A LITTLE BIT AHEAD - FORMING A DETACHED WAVE.

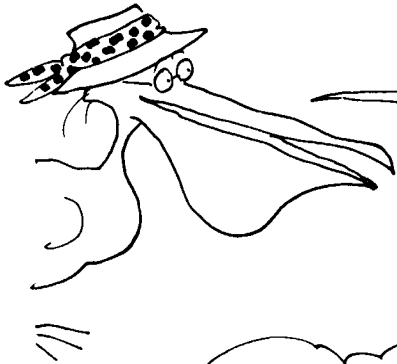
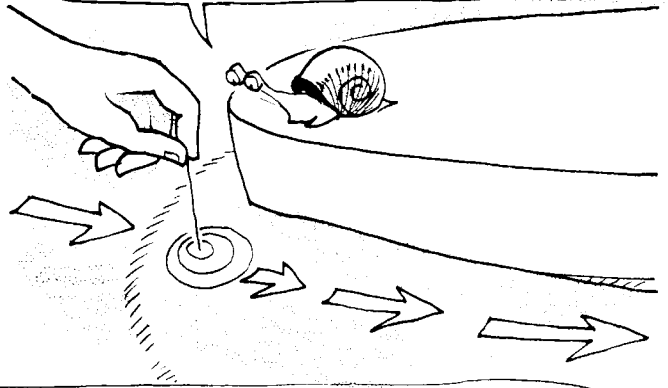


(\*) SEE APPENDIX A (PAGE 71).

THAT'S ONLY TO BE EXPECTED. IN THIS REGION, NEAR A BLUNT BOW, THE SPEED  $V$  FALLS BELOW THE CRITICAL SPEED  $V_s$ .

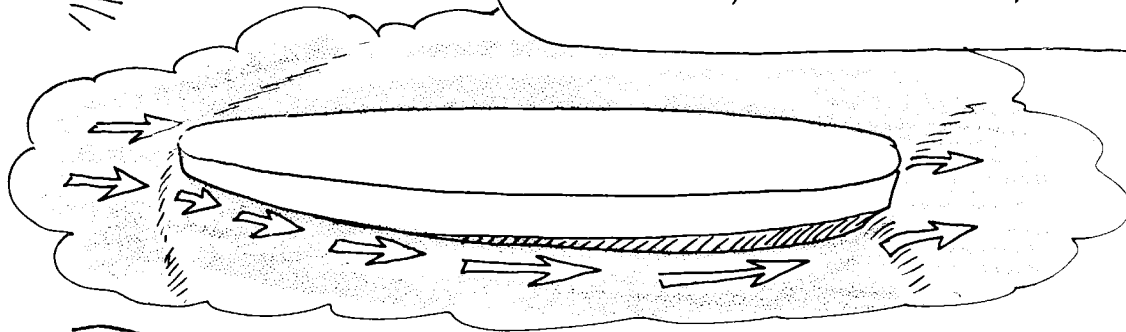


IT'S ALMOST AS IF THE OBJECT USES THE BOW WAVE TO BUILD ITSELF A REGION WHERE  $V$  IS LESS THAN  $V_s$  TO MAKE IT EASIER TO NAVIGATE.



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.



COME ALONG, YE SEEKERS AFTER KNOWLEDGE! DINNER TIME!

IT'S ALL BEGINNING TO MAKE SOME KIND OF SENSE.

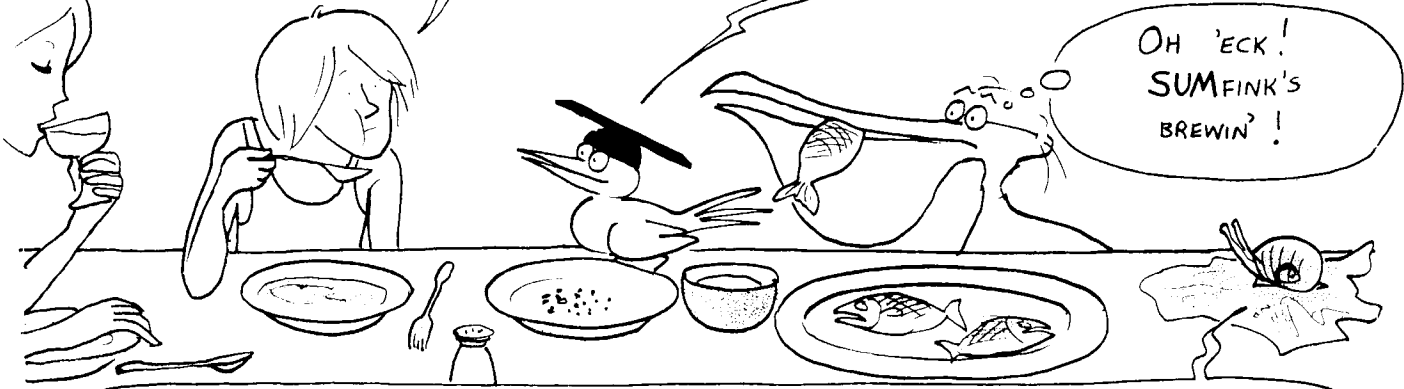




YOU KNOW, IT WOULDN'T BE A BAD THING IF YOU COULD GET RID OF THOSE WAVES.

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!



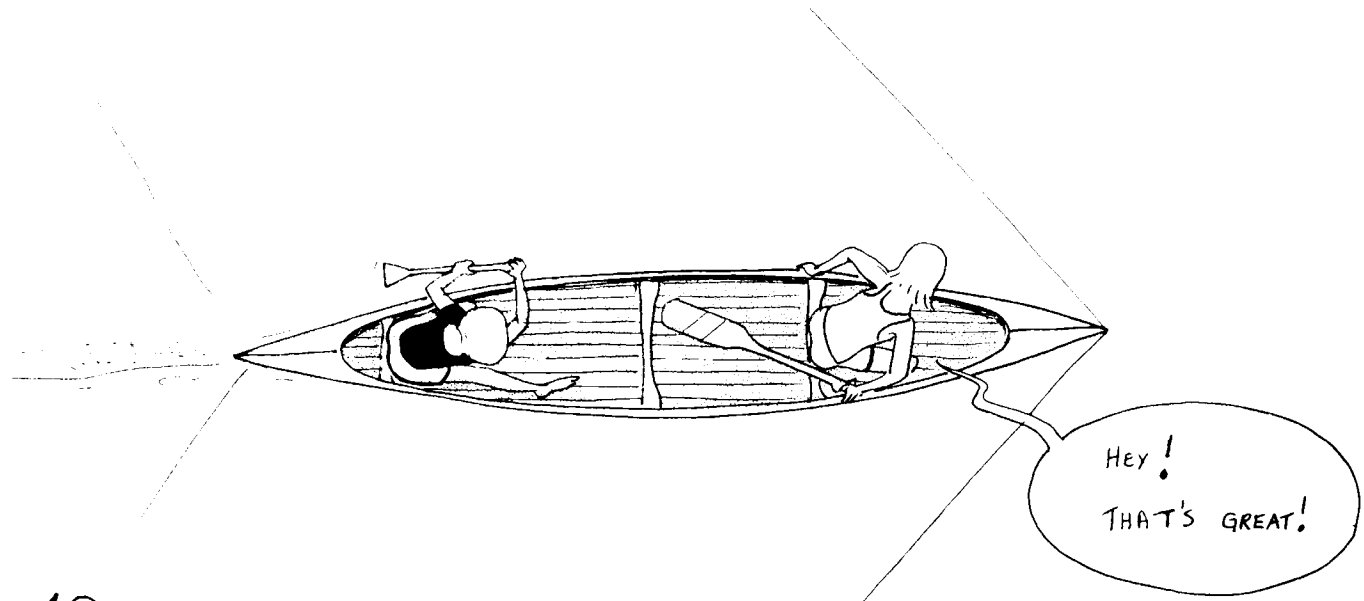
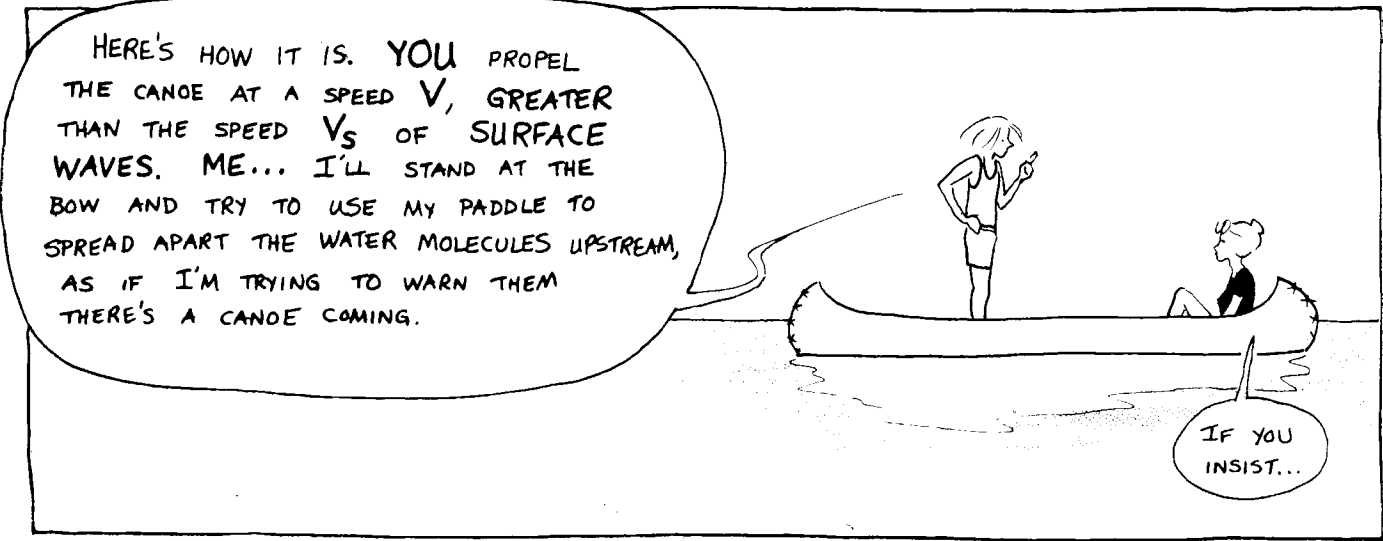
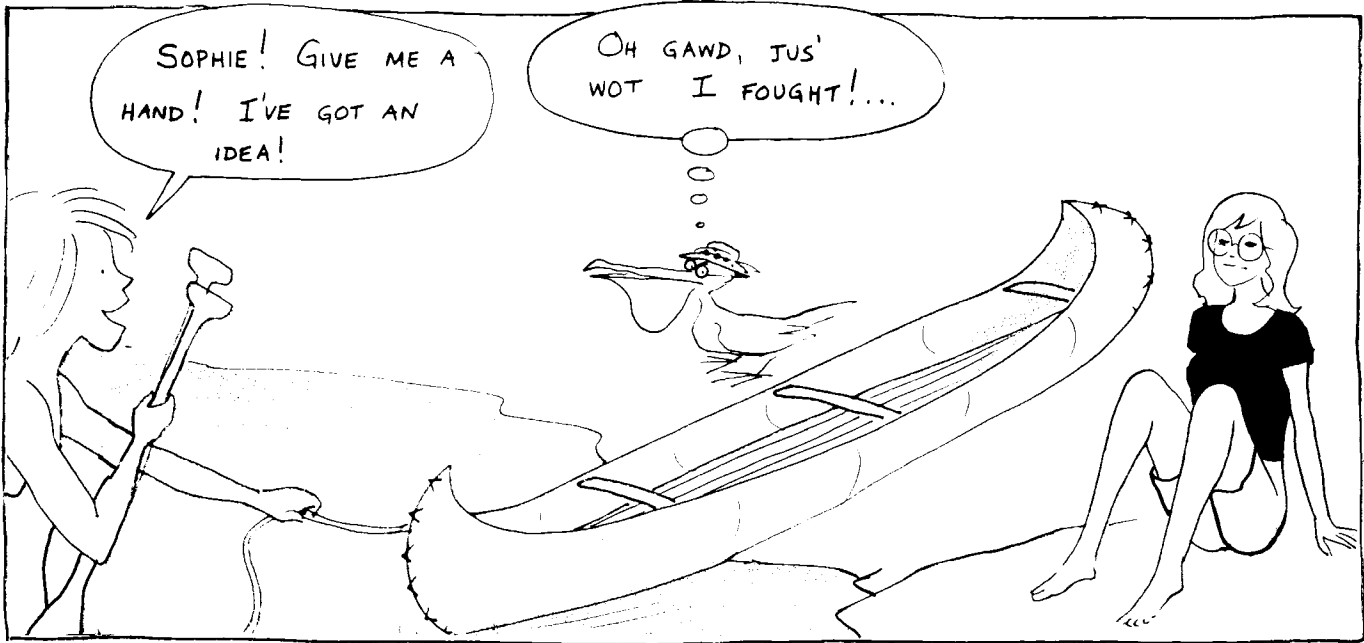
DISHES, ARCHIBALD....

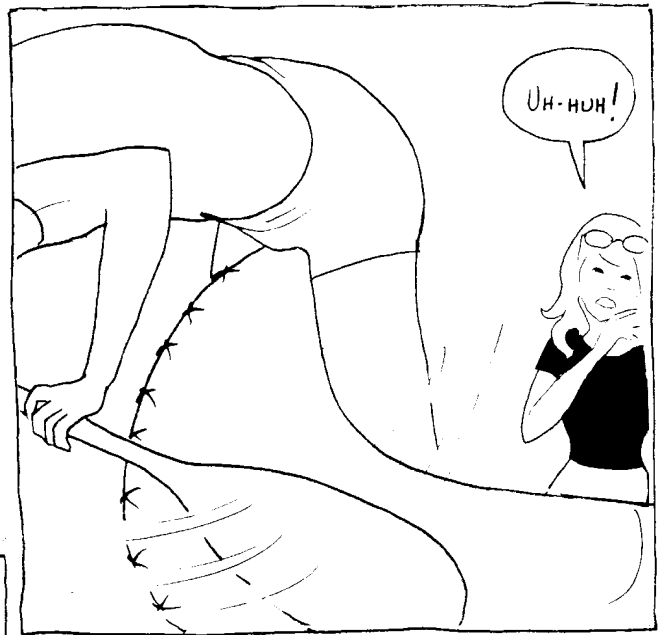
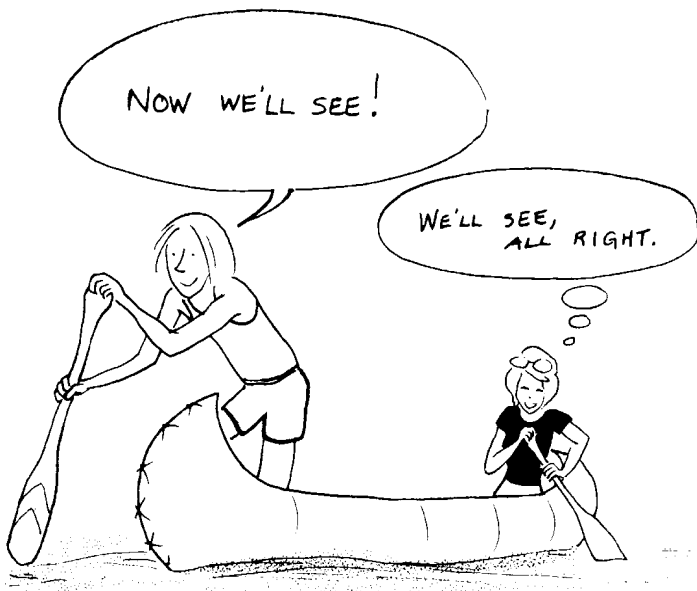
THERE'S GOT TO BE A WAY.

AHA!

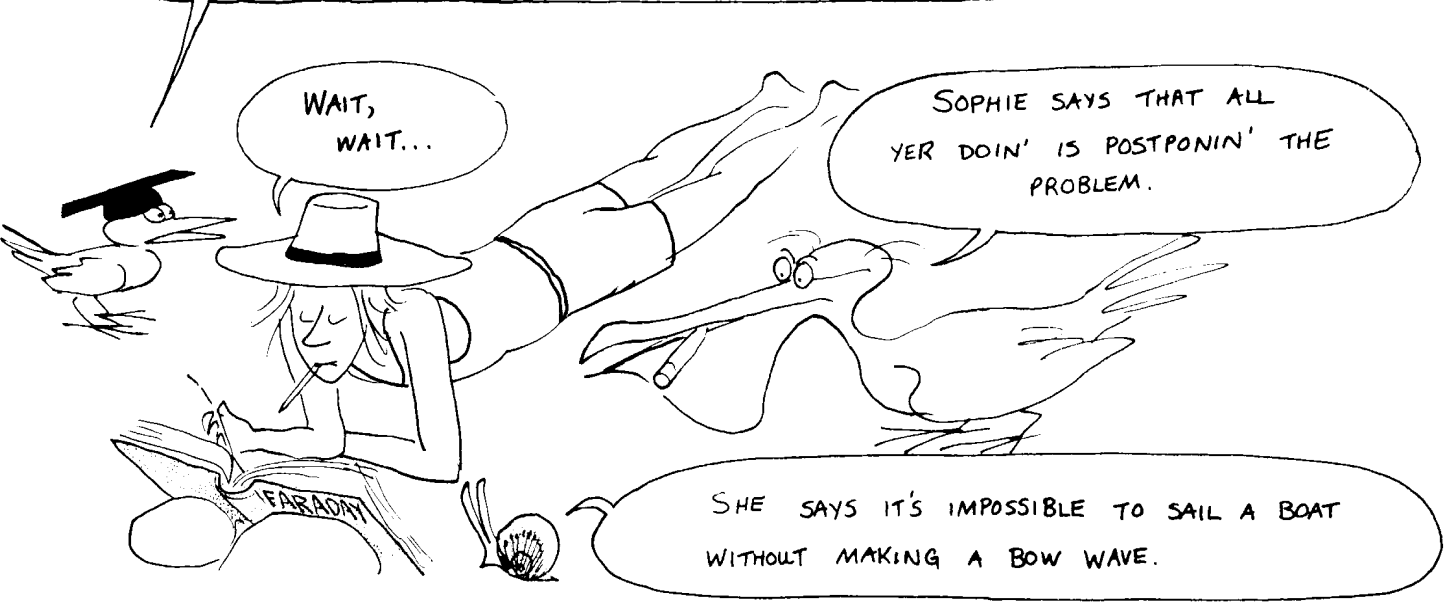
SNAP!







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.

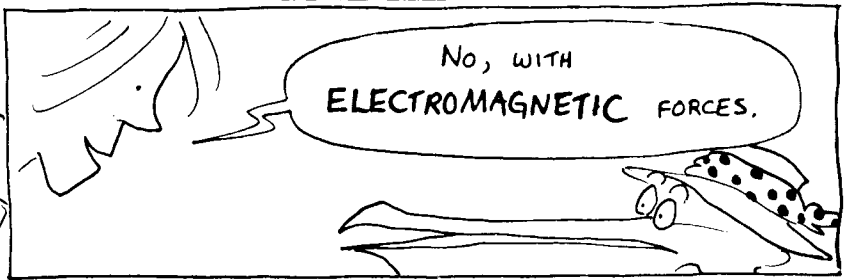


# IN WHICH ARCHIE DISCOVERS MAGNETOHYDRODYNAMICS



YOU CAN ACT AT A DISTANCE ON A FLUID BEFORE YOU REACH IT. IT SAYS SO IN THIS BOOK!

BUT WOT WIV, OLD FRUIT? BLINKIN' MAGIC FORCES?

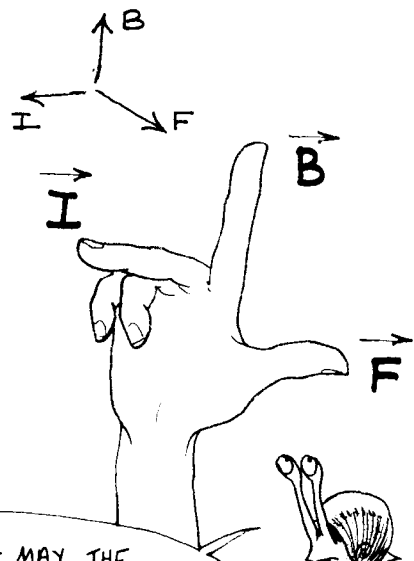


NO, WITH ELECTROMAGNETIC FORCES.

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*

THUMB—MAY THE FORCE BE WITH YOU!

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?

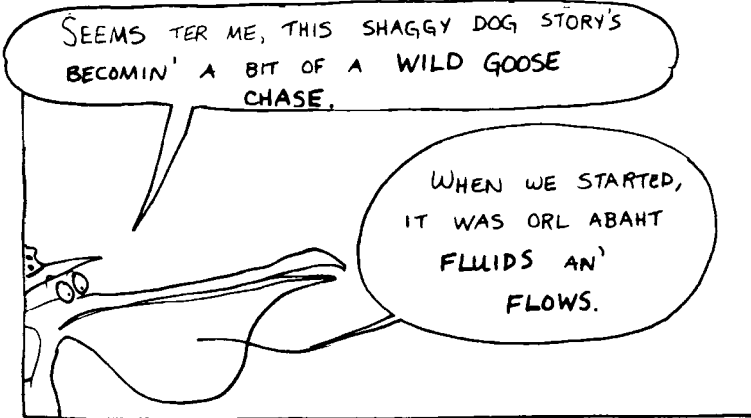
BECAUSE IT CONVERTS ELECTRICAL ENERGY INTO MOTION - OR KINETIC ENERGY.

THE MAGNETIC FIELD VECTOR  $\vec{B}$  AND THE CURRENT VECTOR  $\vec{I}$ , 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  $\vec{I}$  AND THE MAGNETIC FIELD  $\vec{B}$  YOU CAN MAKE THE FLUID ACCELERATE OR DECELERATE AT WILL.

# INTERACTION CRITERION



SEEMS TER ME, THIS SHAGGY DOG STORY'S BECOMIN' A BIT OF A WILD GOOSE CHASE.

WHEN WE STARTED, IT WAS ORL ABAHT FLLUIDS AN' FLOWS.



NAR, IT'S ORL GETTIN' MIXED UP.

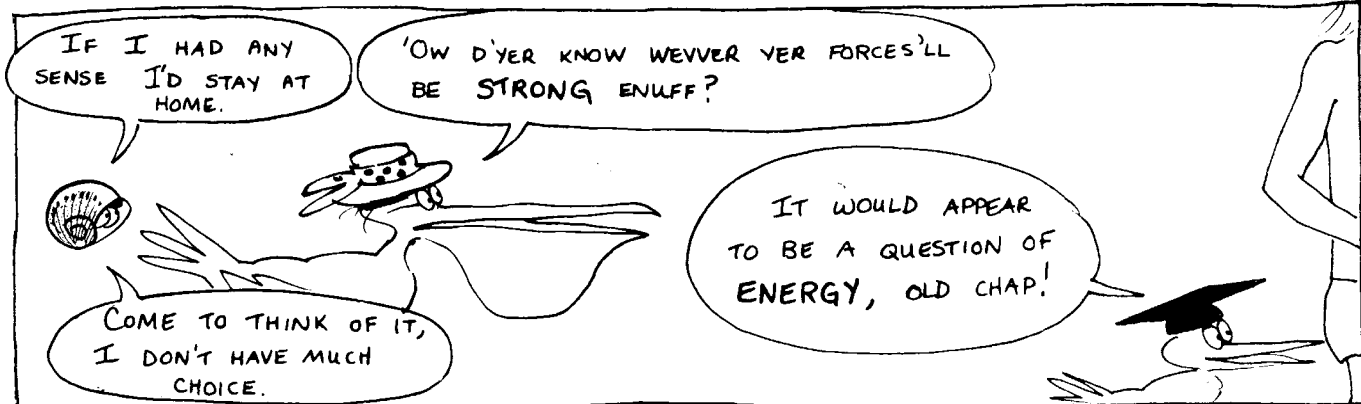
RUDDY 'ECK!



WELL, WELL... AND WHAT ARE WE PLAYING AT TODAY?

I'M TRYING TO CHANGE THE USUAL DATA OF FLUID DYNAMICS BY INTRODUCING EXTRA PARAMETERS: FORCES THAT ACT ON THE FLUID MASS AND DO SO AT A DISTANCE.

DON' ASK ME. I DUNNO NUFFIN'!

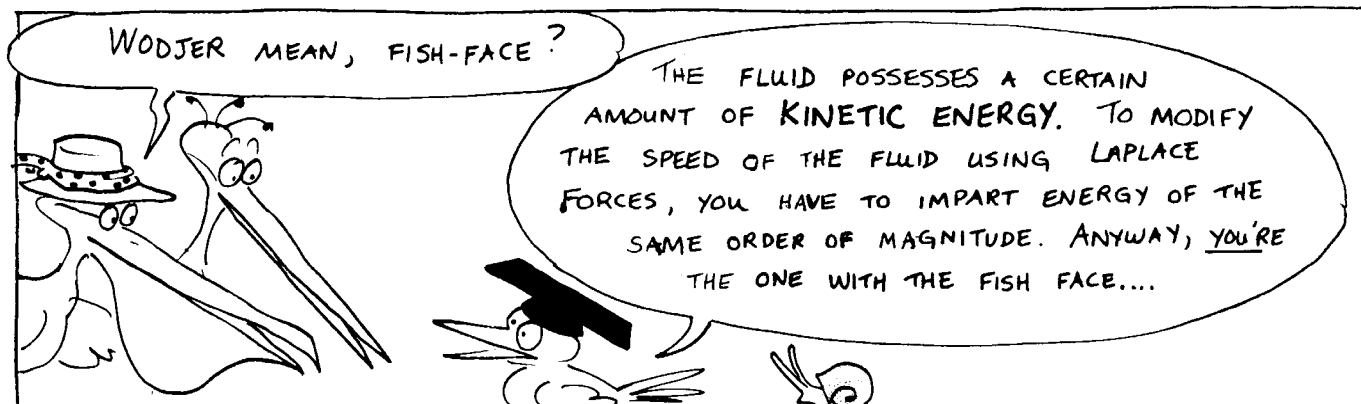


IF I HAD ANY SENSE I'D STAY AT HOME.

'OW D'YER KNOW WEVVER YER FORCES'LL BE STRONG ENUFF?

IT WOULD APPEAR TO BE A QUESTION OF ENERGY, OLD CHAP!

COME TO THINK OF IT, I DON'T HAVE MUCH CHOICE.



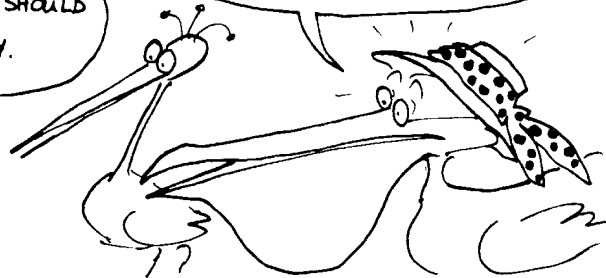
WODJER MEAN, FISH-FACE?

THE FLUID POSSESSES A CERTAIN AMOUNT OF KINETIC ENERGY. TO MODIFY THE SPEED OF THE FLUID USING LAPLACE FORCES, YOU HAVE TO IMPART ENERGY OF THE SAME ORDER OF MAGNITUDE. ANYWAY, YOU'RE THE ONE WITH THE FISH FACE....

... 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!!!

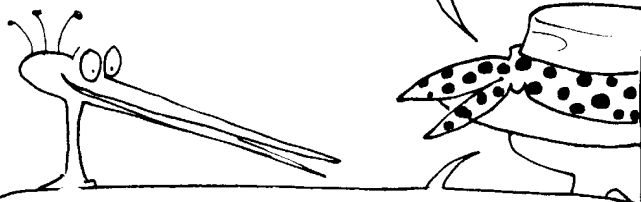


WELL, I MUST SAY, WE REALLY ARE ALL HAVING FUN AND GAMES TODAY, AREN'T WE?



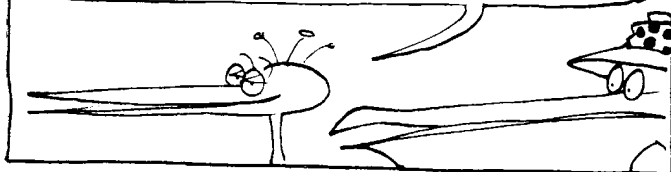
SAY NO MORE, SUNSHINE, SAY NO MORE. YER KNOWS NOT BLINKIN' 'IGGINS IS LIKE. GIVE 'IM AN INCH AN' 'E'LL 'ANG 'IMSELF!

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

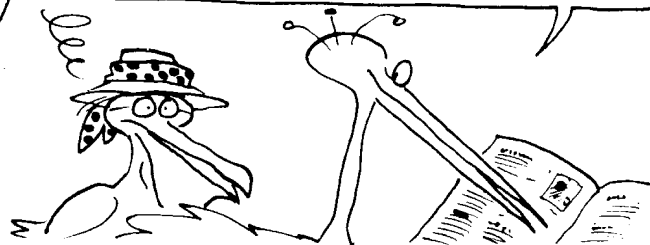


BLEEDIN' NONSENSE ANYWAY, 'IS RUDDY MOSQUITO - 'YDRO-DYNAMO-WOTSIT....

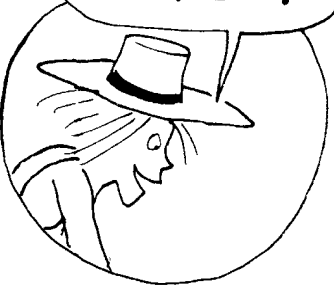
BAH, YOU'RE AFRAID OF YOUR OWN SHADOW! IT'S ALL LOW-VOLTAGE STUFF ANYWAY. THE SKY WON'T FALL IN WITH 40 VOLTS AND 10,000 GAUSS, DAMMIT!



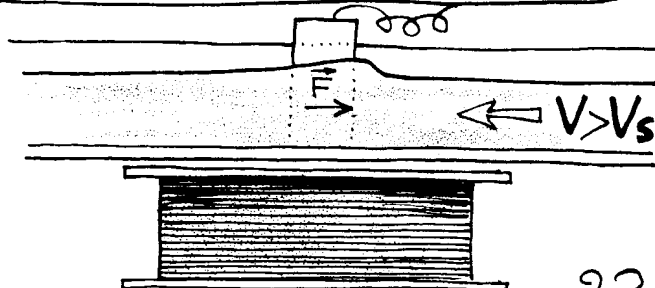
COME ON NOW... MAGNETOHYDRODYNAMICS, ABBREVIATED MHD... YOU'LL EVEN FIND IT IN THE DICTIONARY!



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.





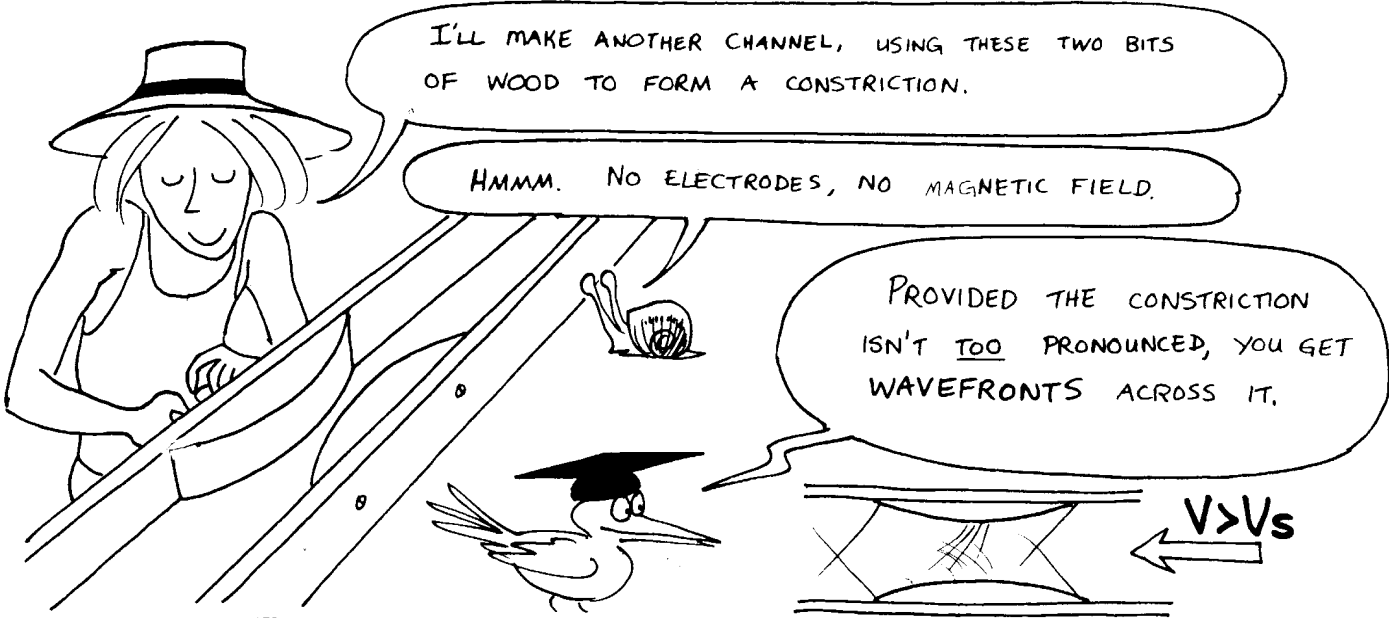
MY WORD, HE HAS TOO!

YUR, GREAT. NOW WOT?

BUT THAT'S CLASSICAL. IT'S BEEN KNOWN FOR YEARS!

# BLOCKAGE

IT'S ABSOLUTELY STANDARD, TOTALLY CLASSICAL PHYSICS.



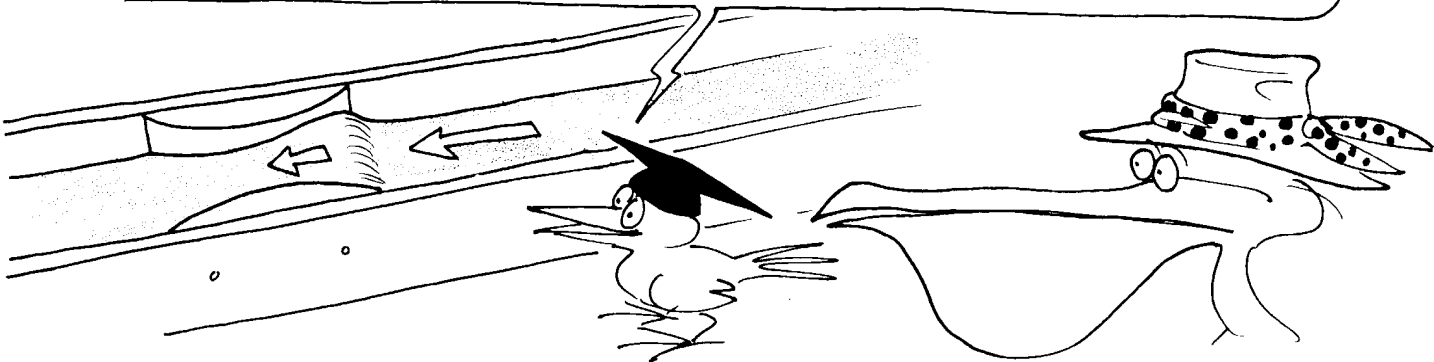
I'LL MAKE ANOTHER CHANNEL, USING THESE TWO BITS OF WOOD TO FORM A CONSTRICTION.

HMMM. NO ELECTRODES, NO MAGNETIC FIELD.

PROVIDED THE CONSTRICTION ISN'T TOO PRONOUNCED, YOU GET WAVEFRONTS ACROSS IT.

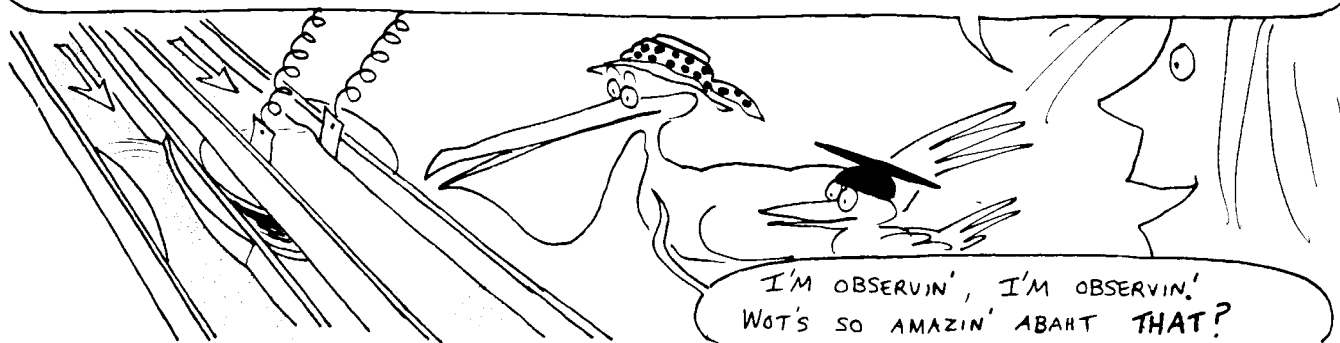
$V > V_s$

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.

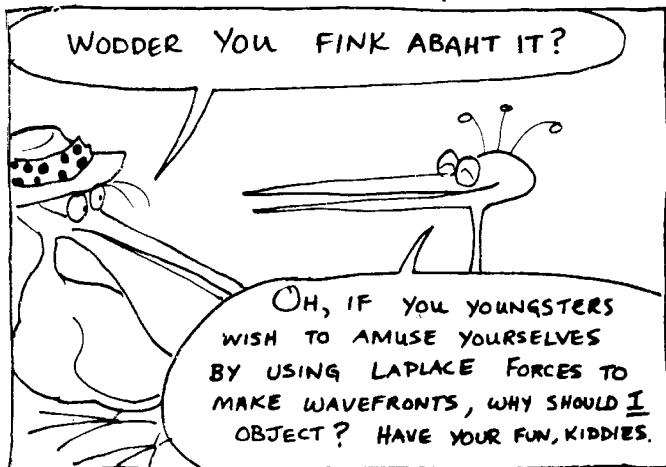




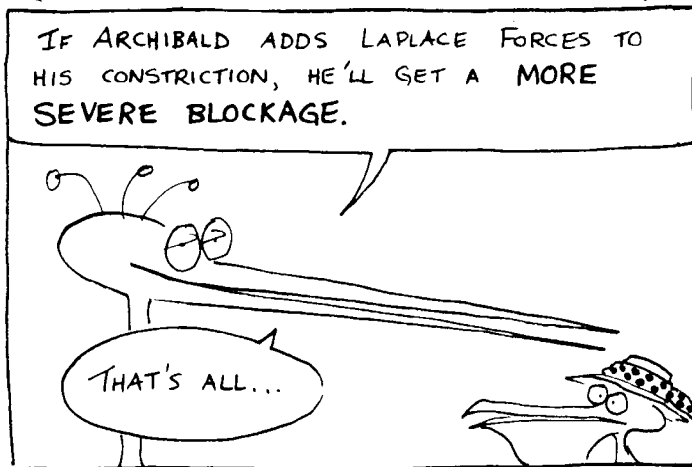
BUT NOW, OBSERVE HOW THE CUNNING EXPERIMENTER HAS USED A MAGNETIC FIELD TO REALIZE THE SAME BLOCKAGE AS THE ONE PRODUCED BY A CONSTRICTION.



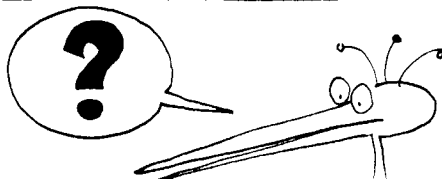
WODDER YOU FINK ABAHT IT?



IF ARCHIBALD ADDS LAPLACE FORCES TO HIS CONSTRICTION, HE'LL GET A MORE SEVERE BLOCKAGE.

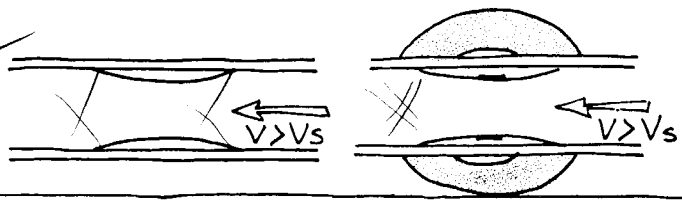
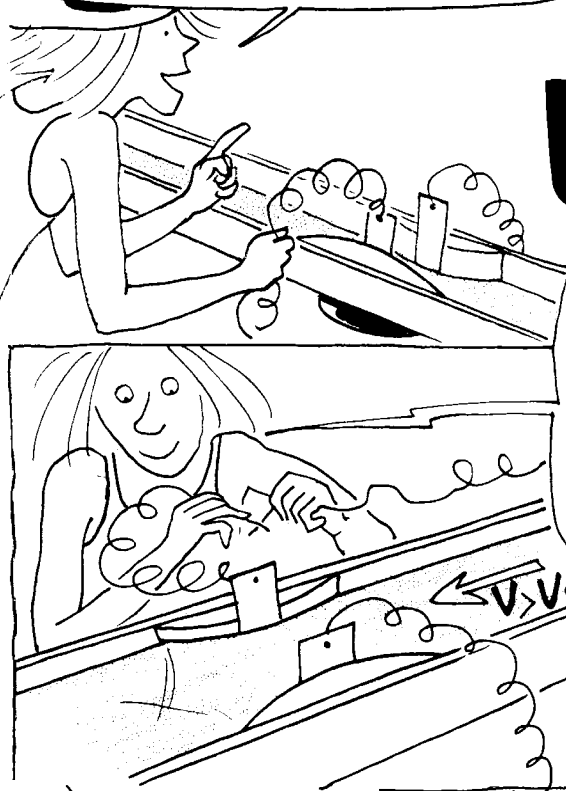


AGREED. BUT... SUPPOSE I INVERT THE LAPLACE FORCE....

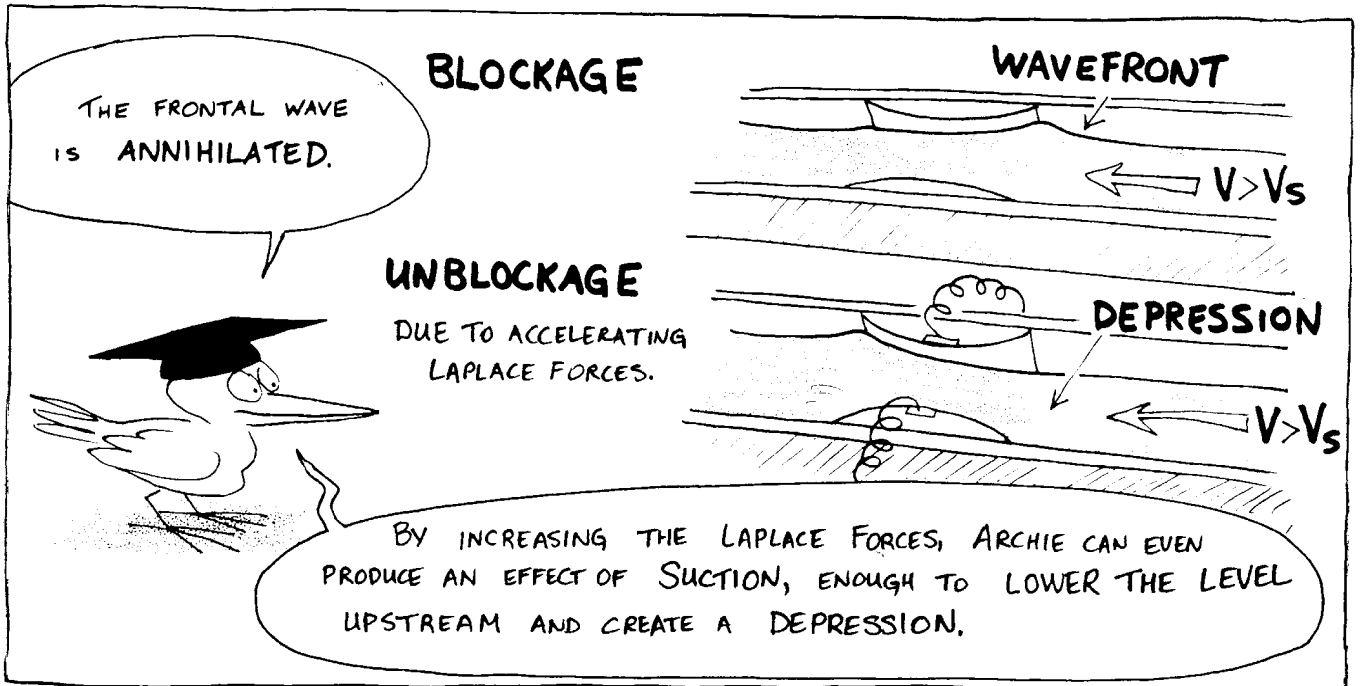
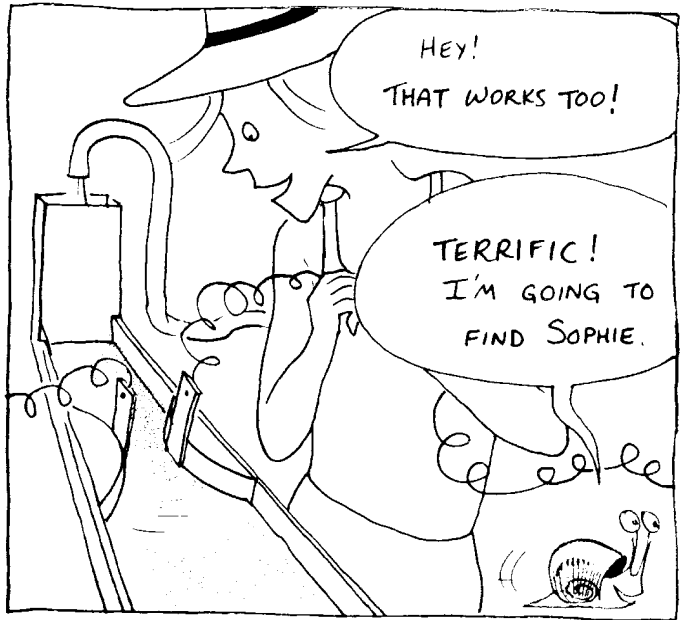
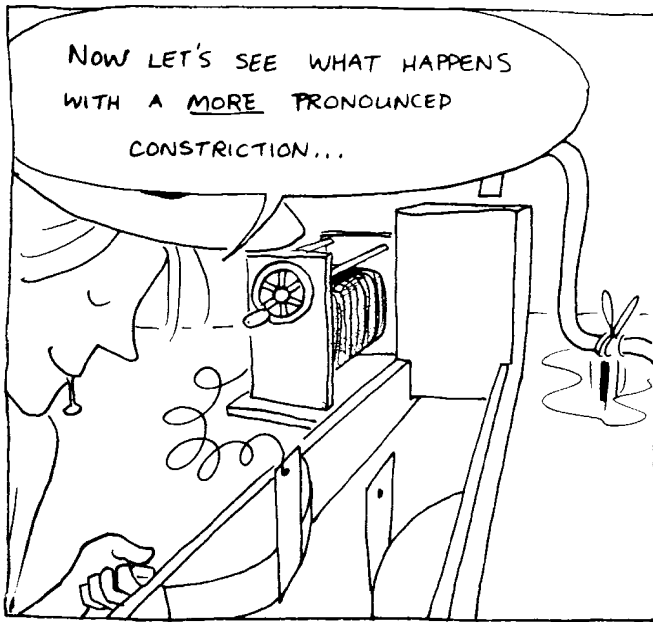


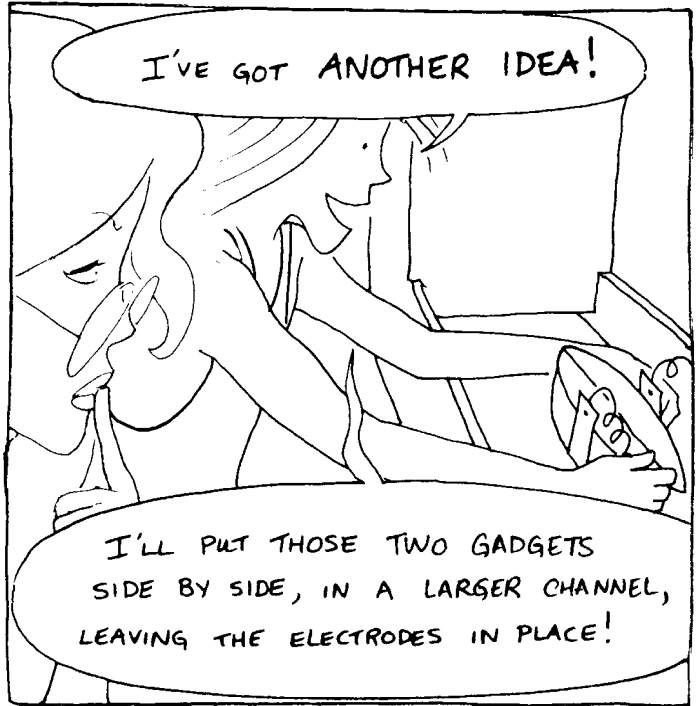
# UNBLOCKAGE

I'LL START WITH A LESS PRONOUNCED CONSTRICTION. TO INVERT THE FORCE, I CAN EITHER INVERT THE MAGNETIC FIELD  $\vec{B}$  OR INVERT THE CURRENT  $\vec{I}$ . HEY PRESTO! IF THE PRODUCT  $IB$  IS LARGE ENOUGH (\*) THEN THIS ACCELERATING LAPLACE FORCE MAKES THE WAVEFRONTS DISAPPEAR UPSTREAM!

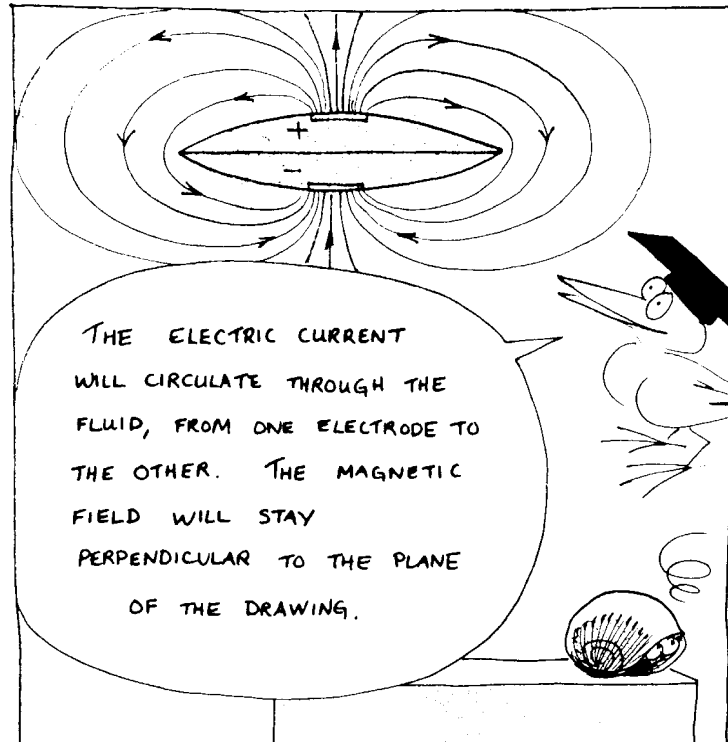


(\*) SEE APPENDIX B (PAGE 71)

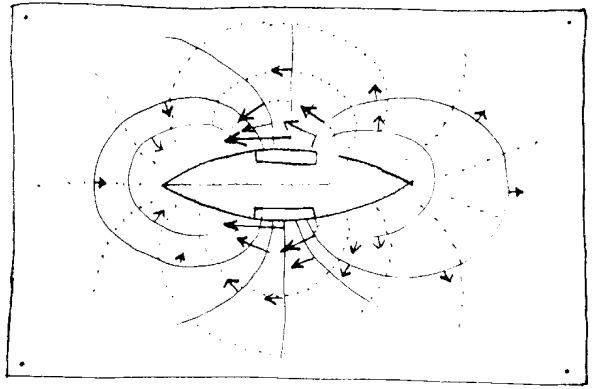




# ANNIHILATION OF THE BOW WAVE

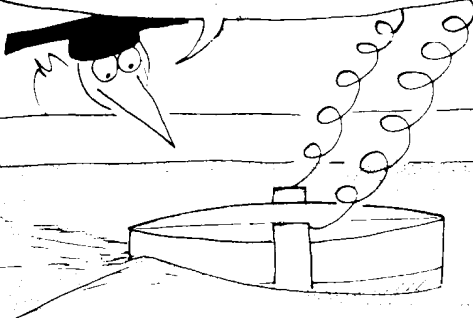


APPLYING THE RIGHT-HAND RULE, I CAN WORK OUT THE FIELD OF FORCES THAT WILL ACT ON THE FLUID.



SHIVER ME TIMBERS!

BY THE SHADES OF MAXWELL'S DEMON!  
ARCHIE HAS ANNIHILATED THE  
**BOW WAVE!**



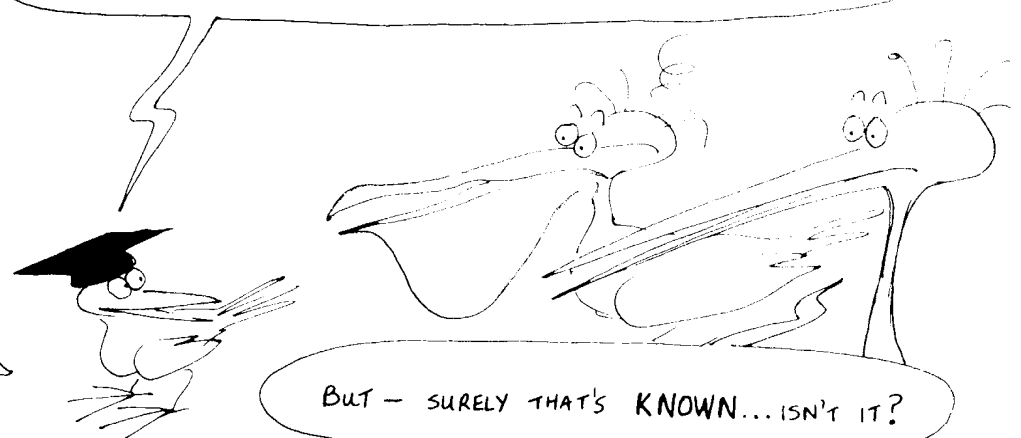
WHAT?

$V > V_s$

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?

NO, IT CERTAINLY ISN'T KNOWN!  
WHAT I'D LIKE TO KNOW IS, WHAT  
DOES HE THINK HE'S PLAYING AT?

BUT YOU WERE SUPPOSED TO BE ENGAGED  
IN SCIENTIFIC POPULARIZATION?

I DON'T UNDERSTAND....

WHEN YOU POPULARIZE THINGS  
THAT AREN'T ALREADY KNOWN,  
DO YOU REALIZE WHAT THAT'S  
CALLED?

IT'S CALLED SCIENTIFIC RESEARCH.

THAT'S REELY TORN IT!

TOO  
TRUE.

LET'S SEE... AHEAD OF A  
MORE STUBBY OBJECT, THE FRONTAL  
WAVE IS DETACHED.

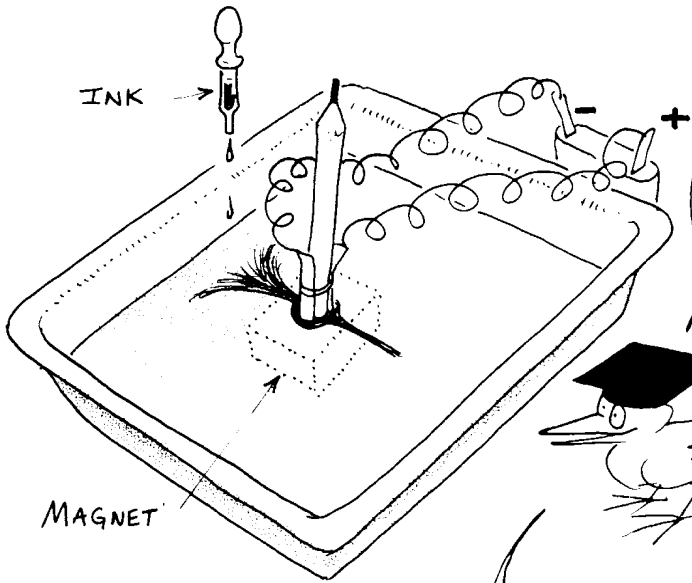
# A DO-IT-YOURSELF MHD ACCELERATOR

AS A LIMITING CASE, THE  
OBJECT COULD JUST BE A  
CYLINDER.

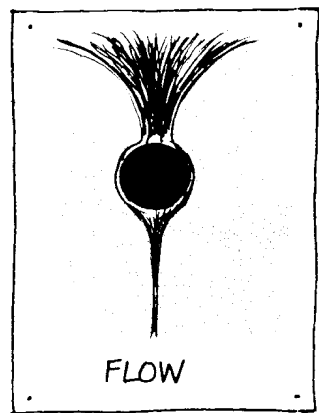
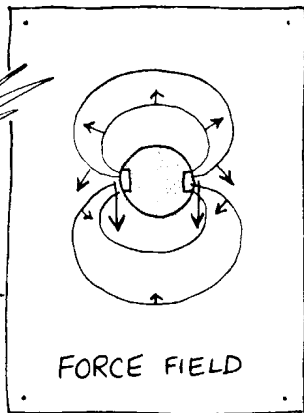
ALL I NEED TO DO IS  
FIX TWO COPPER ELECTRODES  
ON A PENCIL. (\*)

USING A BASIN OF SALTY WATER  
AND A MAGNET, YOU CAN MAKE THE  
PUMPING EFFECT OF LAPLACE FORCES  
BECOME VISIBLE.

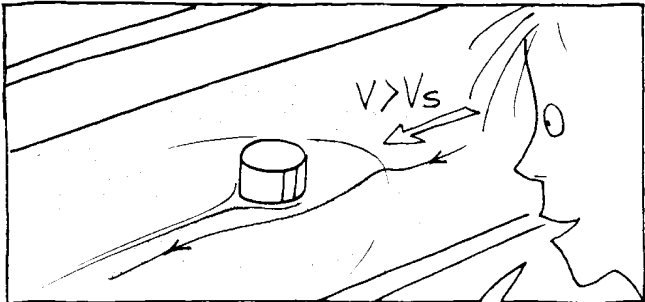
(\*) AN ARRANGEMENT DEvised IN 1976 BY MAURICE VITON.



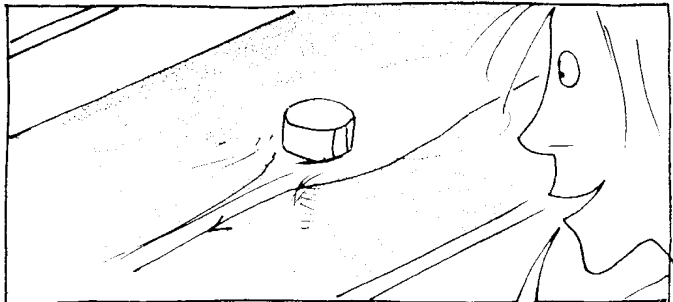
THE MAGNET, UNDERNEATH THE BASIN, PRODUCES A VERTICAL MAGNETIC FIELD  $\vec{B}$ . THE PUMPING EFFECT CAN BE SEEN BY USING A DROP OF INK.



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.

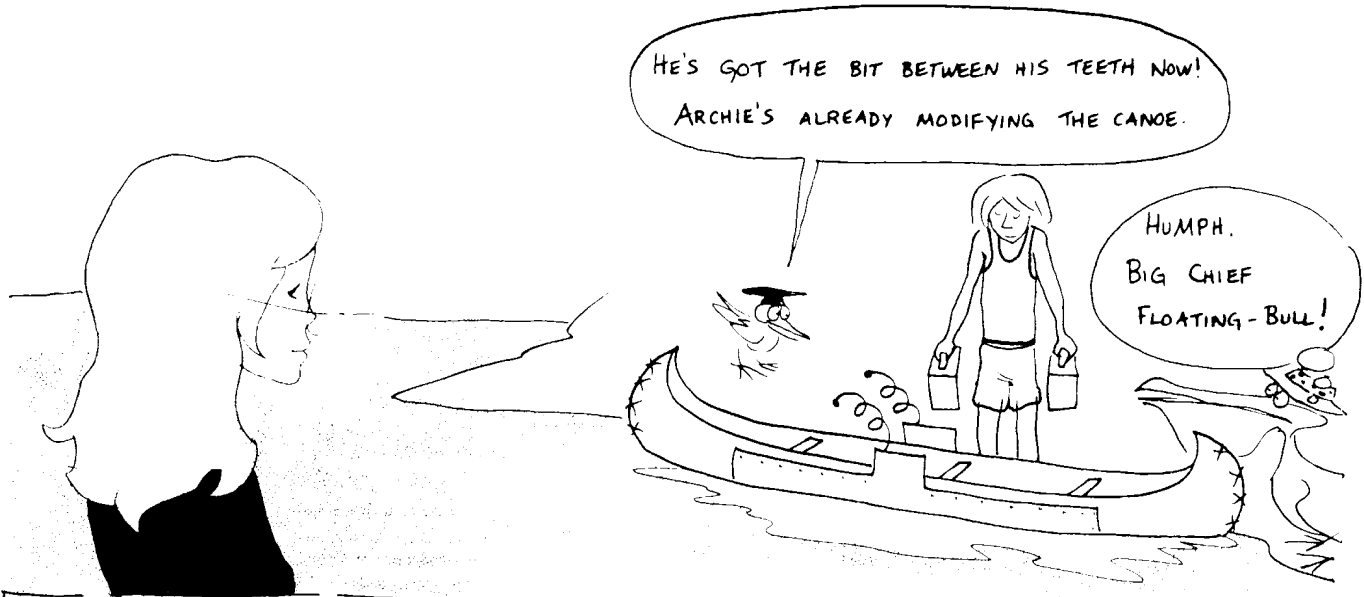
GREAT! NOW FOR THE APPLICATIONS!

WAIT FOR ME, ARCHIE!

WODJER FINK, SOPHIE?

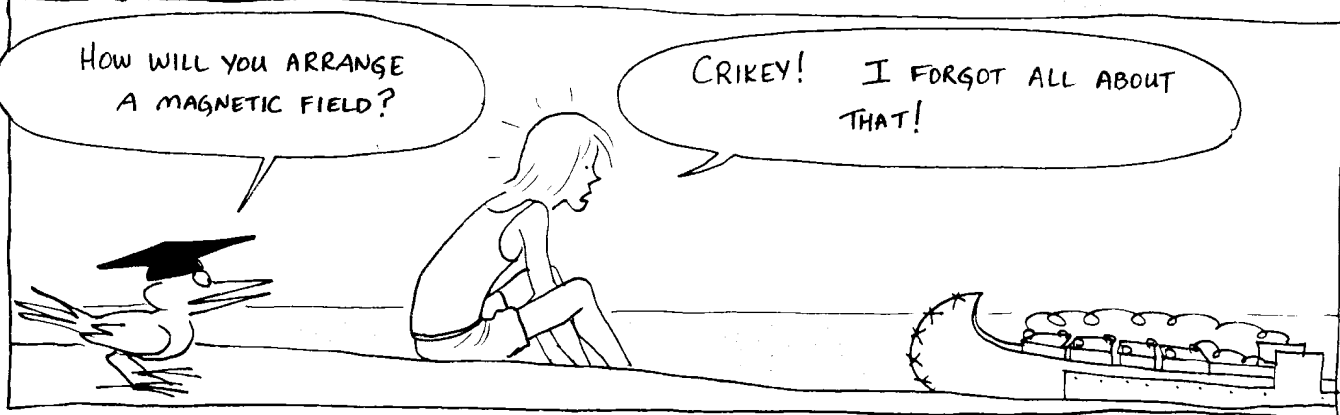


THE LAPLACE FORCES ACT AT A DISTANCE. I THINK ARCHIE HAS DISCOVERED HOW TO "WARN" THE FLUID UPSTREAM.



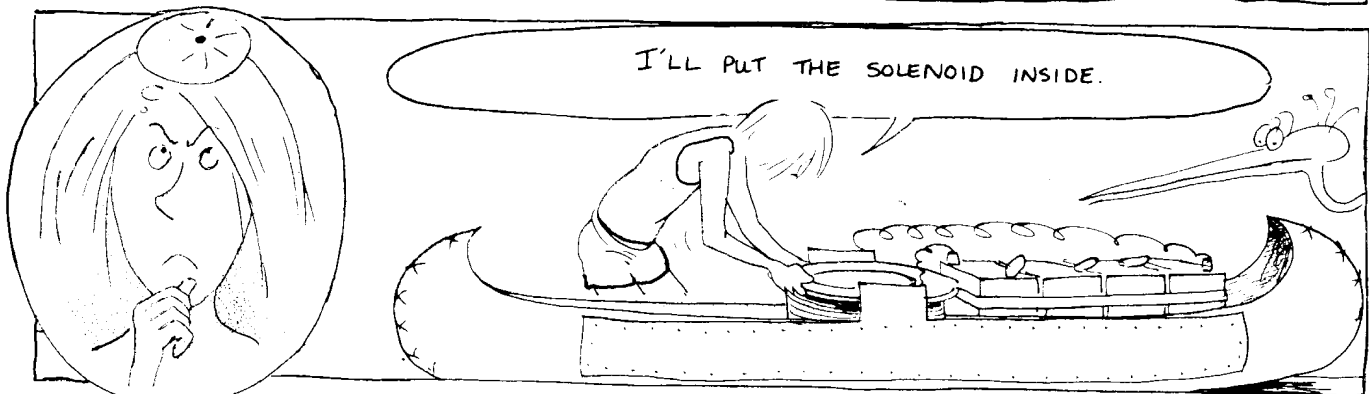
HE'S GOT THE BIT BETWEEN HIS TEETH NOW!  
ARCHIE'S ALREADY MODIFYING THE CANOE.

HUMPH.  
BIG CHIEF  
FLOATING-BULL!

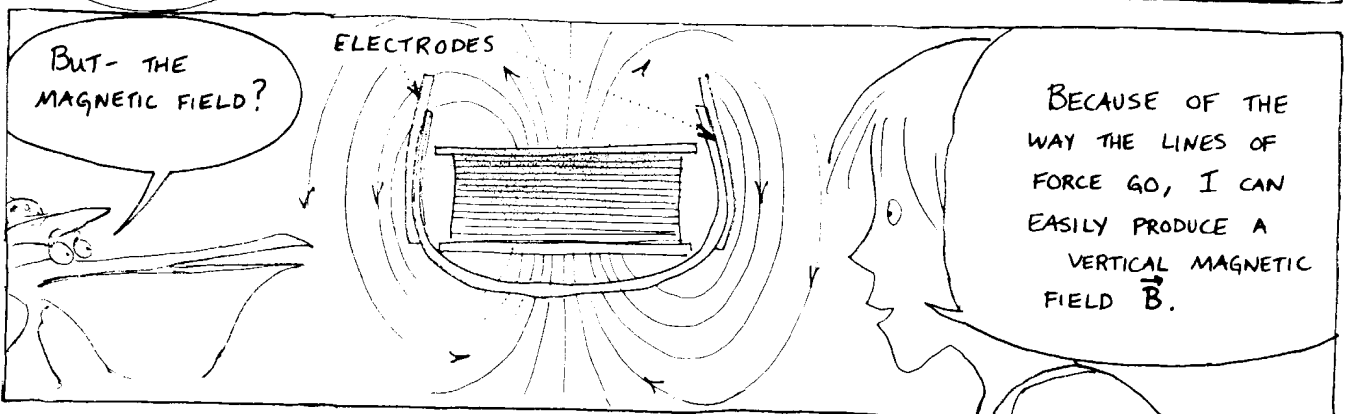


HOW WILL YOU ARRANGE  
A MAGNETIC FIELD?

CRIKEY! I FORGOT ALL ABOUT  
THAT!



I'LL PUT THE SOLENOID INSIDE.



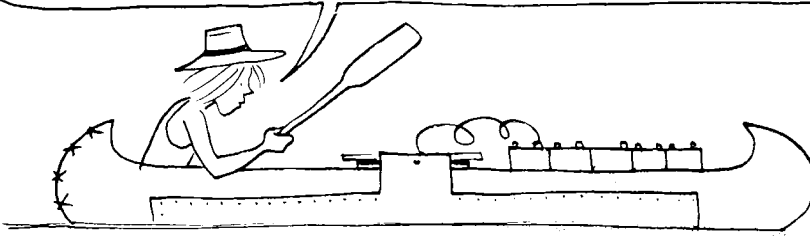
BUT- THE  
MAGNETIC FIELD?

ELECTRODES

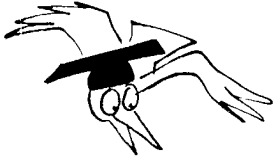
BECAUSE OF THE  
WAY THE LINES OF  
FORCE GO, I CAN  
EASILY PRODUCE A  
VERTICAL MAGNETIC  
FIELD  $\vec{B}$ .

# MHD PROPULSION

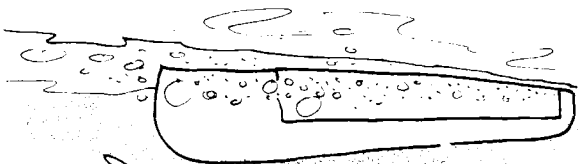
THE CUNNING EXPERIMENTER SETS OFF INTO THE UNKNOWN ABOARD HIS BOW WAVE ANNIHILATOR. ALL HE MUST DO NOW IS TO PADDLE THE CANOE AT A SPEED  $V$  GREATER THAN THE SPEED  $V_s$  OF SURFACE WAVES.



MY WORD! THE CANOE'S SAILING ALL BY ITSELF!

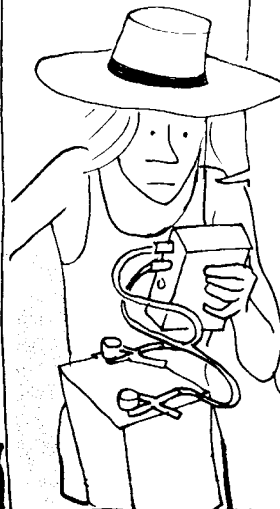


NORMAL ENOUGH. THE MHD SYSTEM PUMPS WATER TOWARD THE BACK, ALTERING THE BALANCE OF PRESSURE ON THE HULL. THE RESULT IS A PUSH.



GEE! THAT BABY REALLY MOVES!

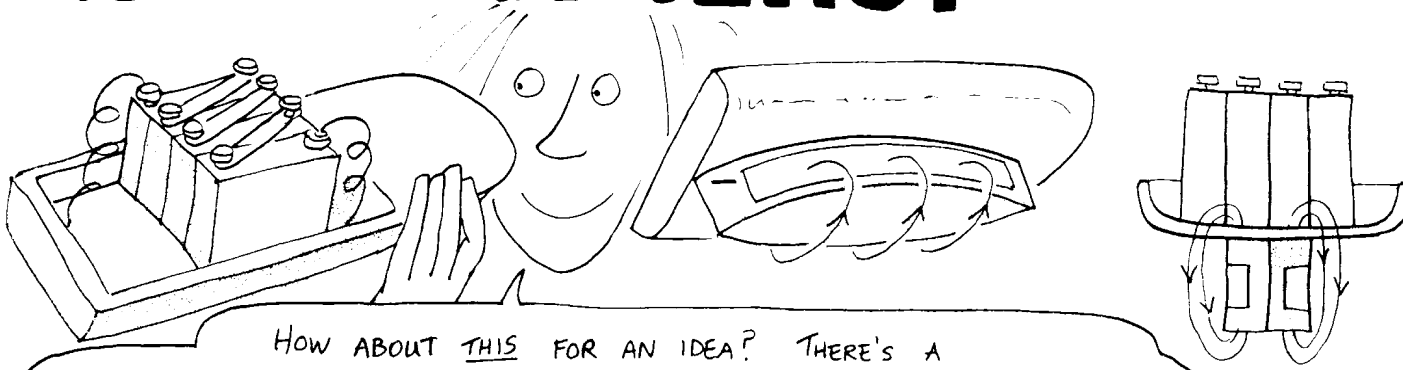
ELECTROLYTE CRAFT USUALLY DO.



DARN IT! THE CONFOUNDED BATTERY'S FLAT ALREADY. THAT SOLENOID USES AN AWFUL LOT OF ENERGY. I'LL TRY A SMALL MODEL WITH PERMANENT MAGNETS.



# MHD EFFICIENCY



How about this for an idea? There's a permanent magnet under the hull, and the electrodes are connected to a battery.



Heck, it doesn't go very fast!  
Only one gram of push...



It takes as much power as a steam-iron. (\*)



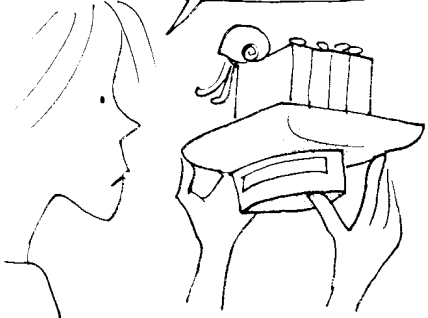
Contrariwise, suppose I apply the same power to a conventional electric motor.



It goes like the wind!



What happened?



Your magnetic field is too weak - the method of propulsion is highly inefficient.



(\*) SEE APPENDIX C (PAGE 71)

HUH? WHAT D'YOU MEAN?

THE BLADES OF THIS PROPELLER ARE INCLINED AT A DEFINITE ANGLE.

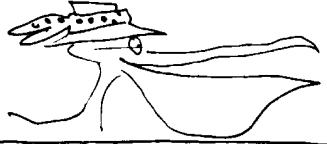
WHAT WOULD YOU THINK OF A PROPELLER THAT WAS INCLINED AT AN ANGLE OF A FRACTION OF A DEGREE?

IT WOULD BE INEFFICIENT. ONLY A TINY AMOUNT OF THE POWER WOULD BE USED FOR PROPULSION. MOST OF IT WOULD BE DISSIPATED IN THE FORM OF HEAT, THROUGH FRICTION.

AND THAT'S EXACTLY WHAT HAPPENS WITH YOUR MHD PROPULSION. SUPPOSE THE CURRENT  $I$  REPRESENTS THE NUMBER OF TURNS AND THE FIELD  $B$  THE ANGLE OF THE BLADES.

YOUR ANGLE IS TOO SMALL! ALL YOU'RE DOING IS HEATING THE WATER...

WITH PERMANENT MAGNETS, THE BEST YOU CAN HOPE FOR IS AN EFFICIENCY OF A FEW MILLIONTHS. (\*) IN SEAWATER, BEFORE AN MHD MOTOR BEGINS TO BE INTERESTING, YOU NEED A MAGNETIC FIELD 250 TIMES GREATER: ABOUT 20 TO 25 TESLAS.



BUT WE KNOW HOW TO MAKE STRONG MAGNETIC FIELDS, DON'T WE?

SUPPOSE YOU COULD GET YOUR 25 TESLAS. THEN THE BOAT WOULD HAVE TO BE MUCH BIGGER AND SO WOULD THE DISTANCE BETWEEN THE ELECTRODES. IF IT WERE TEN METERS, THE GENERATOR WOULD HAVE TO PUT OUT 10,000 VOLTS.

YOUR HYDRODYNE OUGHT TO BE RENAMED THE GYMNOTID. (\*\*)

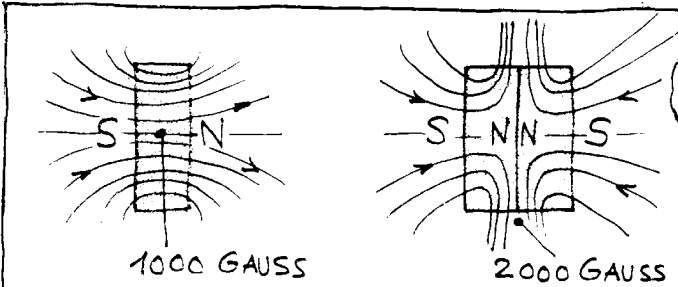
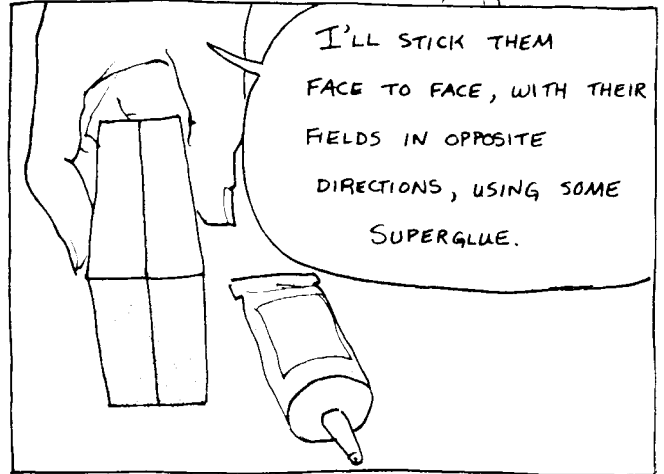
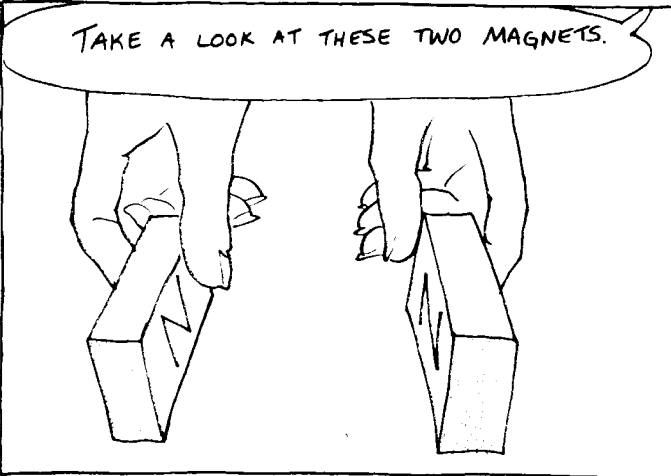
SO NONE O' THAT 'OLDS ANY WATER, RIGHT?

(\*) SEE APPENDIX C (PAGE 71)  
 (\*\*\*) A GYMNOTID IS A ABLE TO PRODUCE AN ELECTRICAL DISCHARGE OF 300 VOLTS.

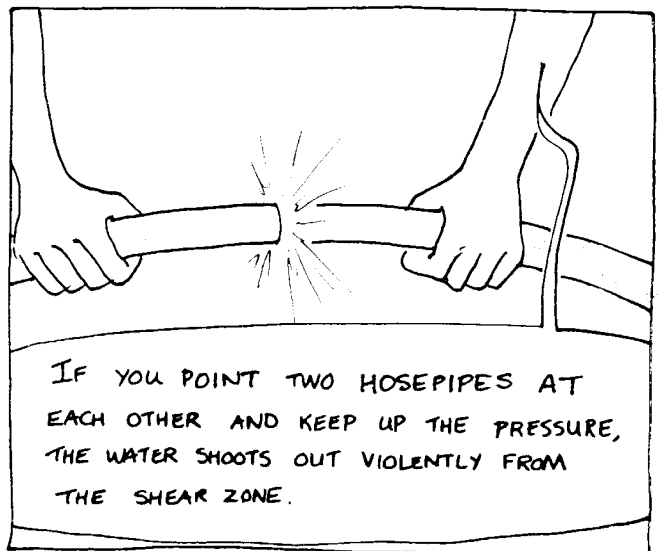
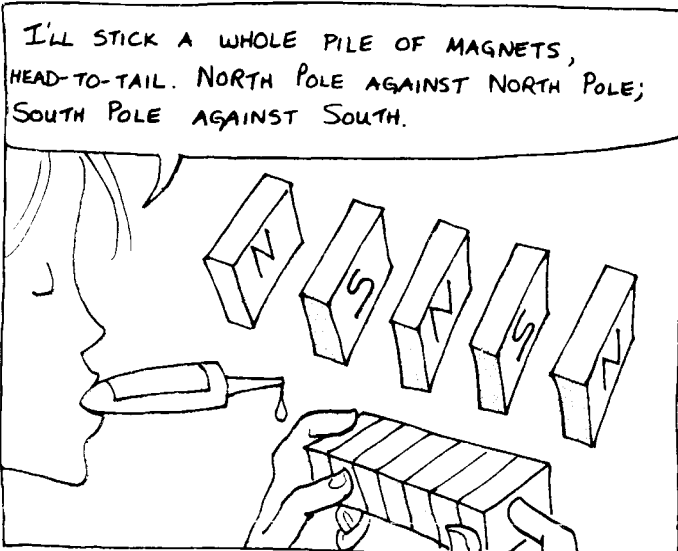
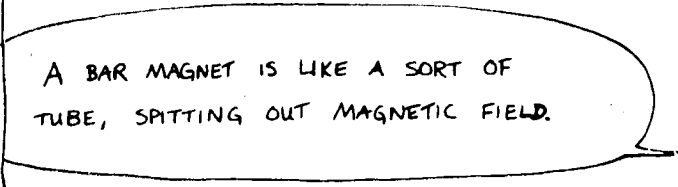
# THE PARIETAL ACCELERATOR

SOPHIE, I'VE WORKED OUT HOW TO OPERATE AT LOW VOLTAGE.

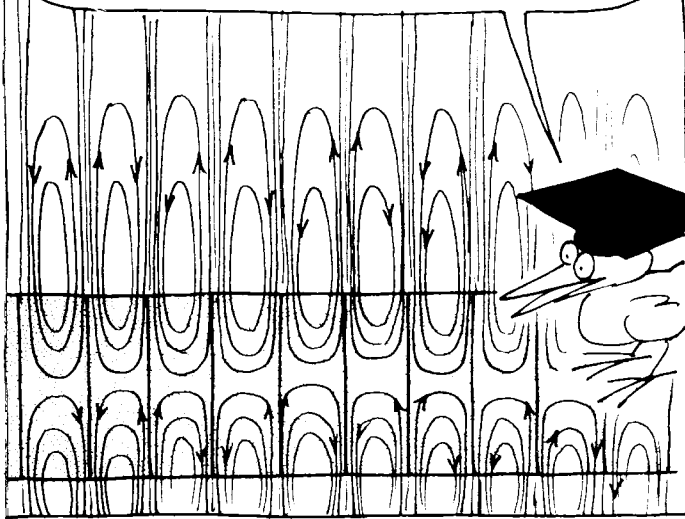
OH, 'ECK...



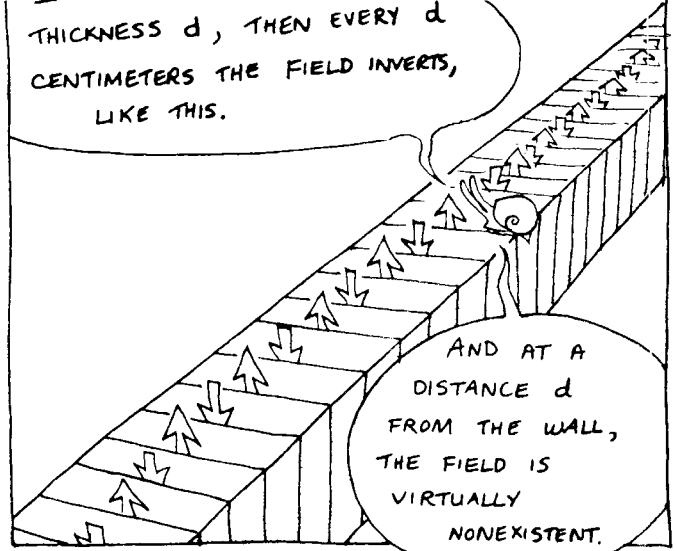
FASCINATING, FASCINATING. BECAUSE IT'S CONCENTRATED IN THE PLANE OF THE JOIN, THE FIELD IS ALMOST DOUBLED.



HERE'S HOW THE LINES OF FORCE LOOK.

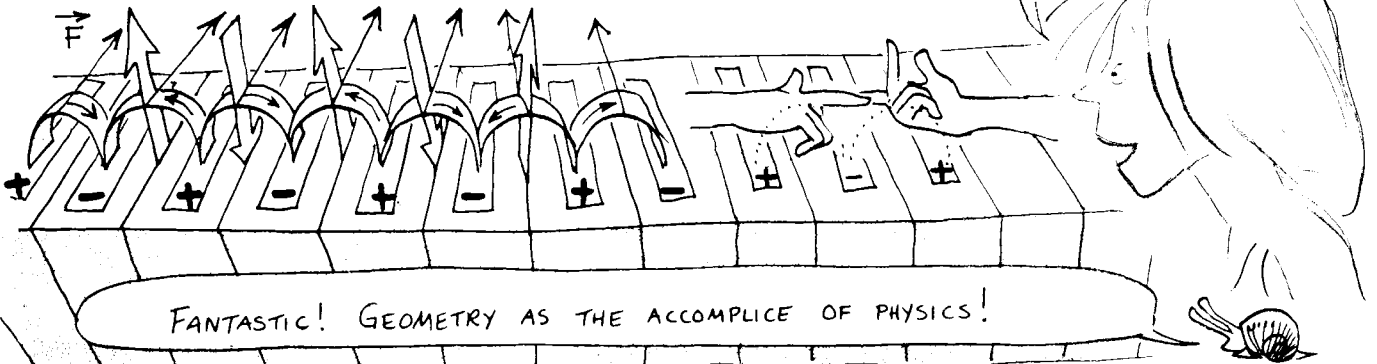


IF THE MAGNETS HAVE THICKNESS  $d$ , THEN EVERY  $d$  CENTIMETERS THE FIELD INVERTS, LIKE THIS.



AND AT A DISTANCE  $d$  FROM THE WALL, THE FIELD IS VIRTUALLY NONEXISTENT.

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  $d$ .

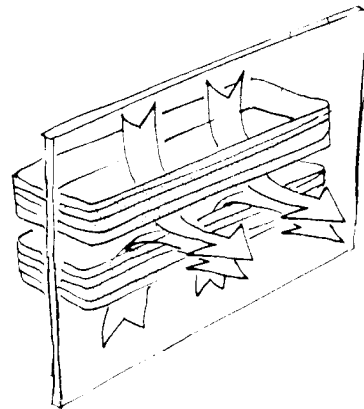
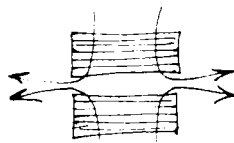


FANTASTIC! GEOMETRY AS THE ACCOMPLICE OF PHYSICS!

TO CREATE A MAGNETIC FIELD, YOU NEED ENERGY. BY ACTING ONLY IN A VERY THIN REGION AROUND THE WALL, YOU REDUCE CONSIDERABLY THE VOLUME TO BE MAGNETIZED, HENCE THE ENERGY REQUIRED, WHICH IS PROPORTIONAL.



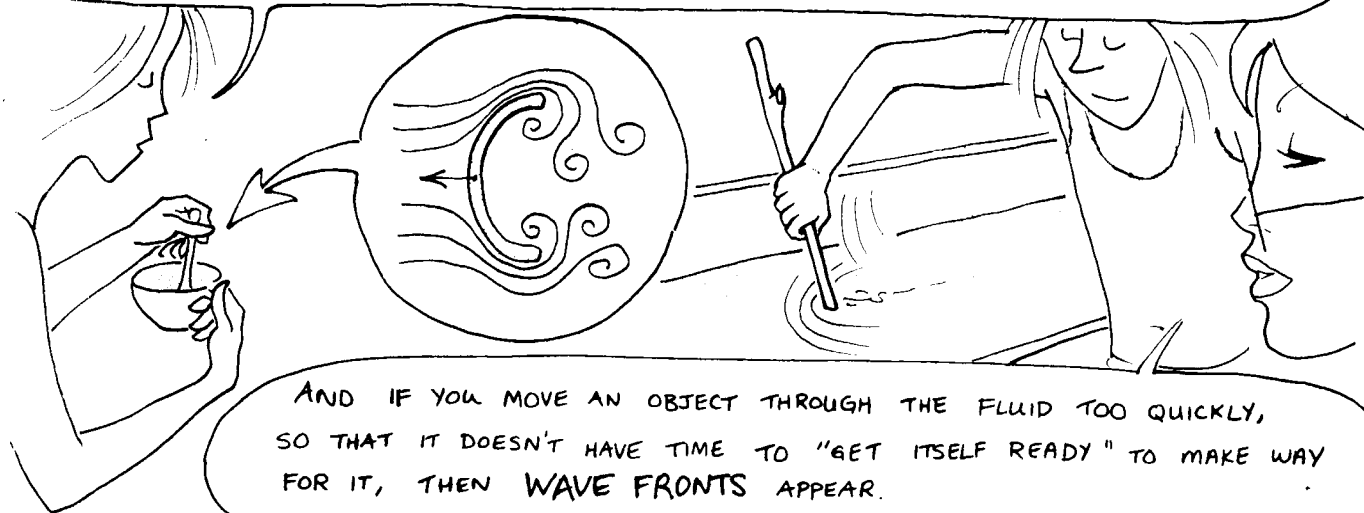
I CAN ALSO REPLACE THE MAGNETS BY COILS.



HERE'S A SIMPLER SYSTEM, USING TWO ELECTRODES.

# A NEW KIND OF FLUID MECHANICS

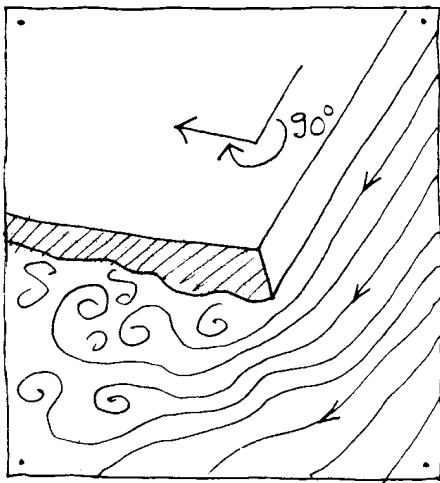
WHENEVER YOU MAKE A FLUID DO SOMETHING THAT MOVES IT, IT REACTS. FOR EXAMPLE, IF YOU TRY TO MAKE IT TWIST TOO ABRUPTLY, IT "COMES UNSTUCK."



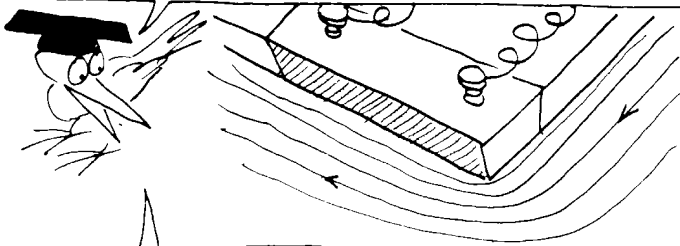
AND IF YOU MOVE AN OBJECT THROUGH THE FLUID TOO QUICKLY, SO THAT IT DOESN'T HAVE TIME TO "GET ITSELF READY" TO MAKE WAY FOR IT, THEN WAVE FRONTS APPEAR.

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



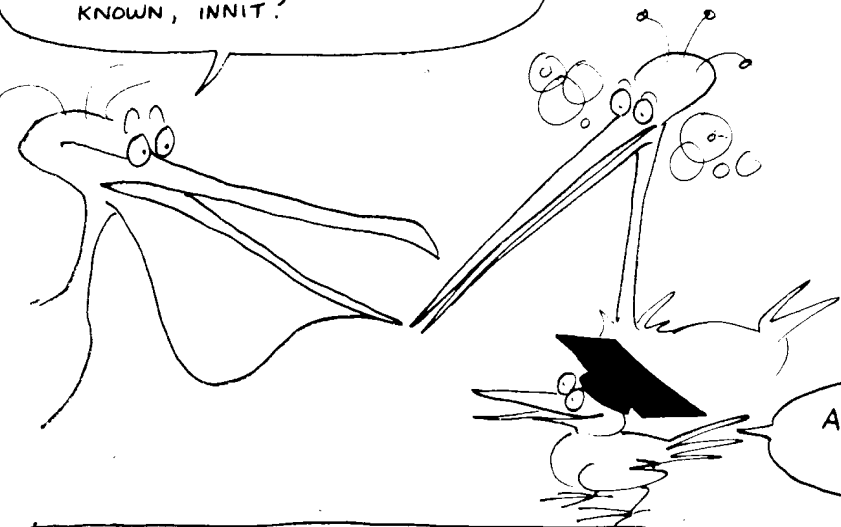


FOR EXAMPLE: IN CLASSICAL FLUID MECHANICS, A SHARP CORNER PRODUCES A LOSS OF ADHESION, GENERATING TURBULENCE.



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

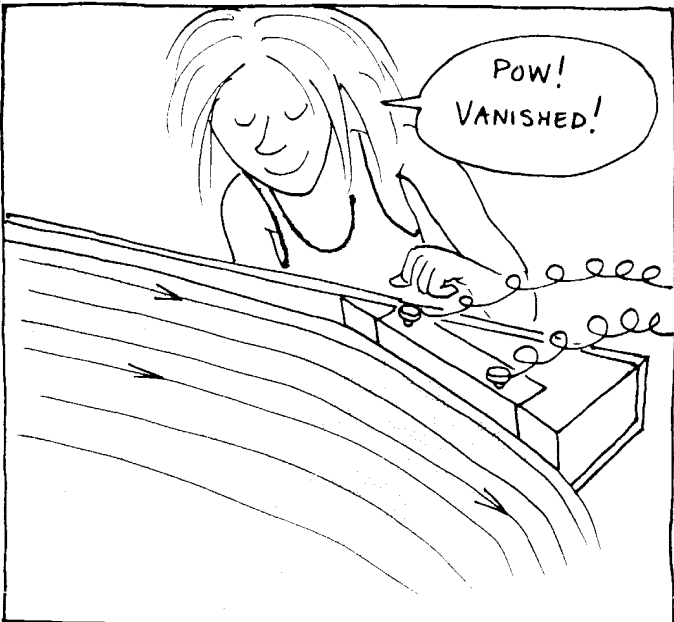
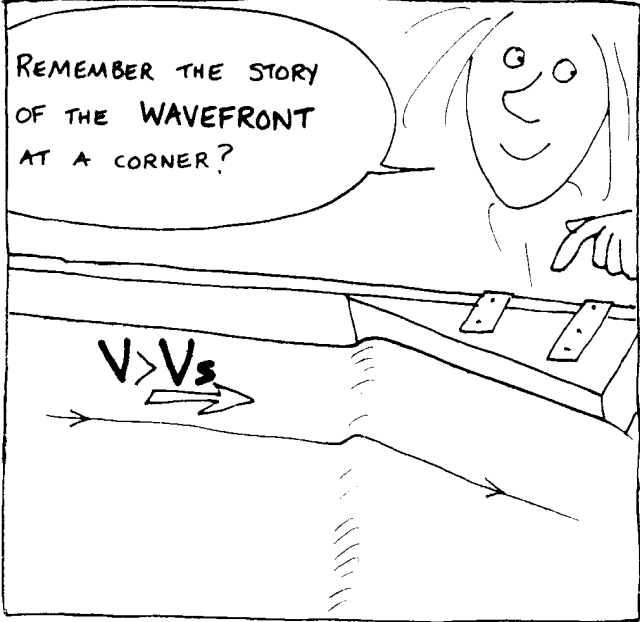
BUT... IT'S CRAZY! IT'S ALL KNOWN, INNIT?



EITHER WAY, YOU WIN!



A WHIFF OF MADNESS WAFTS THROUGH THIS TALE...



YOU SEE, IT'S LOOKING ENTIRELY FEASIBLE TO TAME A FLOW. WHEREVER THE FLUID STARTS TO SLOW DOWN, YOU SPEED IT UP AGAIN; AND WHEN IT RUSHES AHEAD, YOU REIN IT BACK IN.

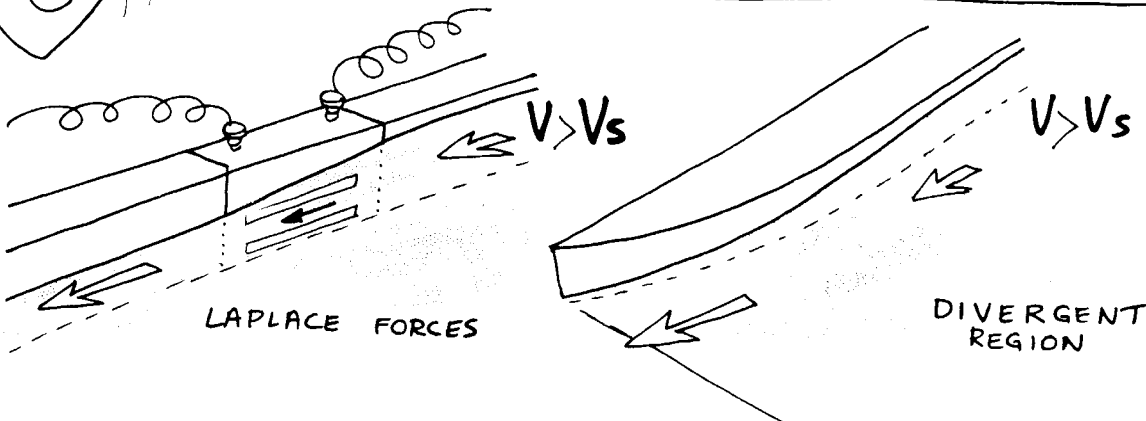
NOTHING ABOUT IT IN HERE....

GASP!

# COMPRESSION WAVES EXPANSION WAVES

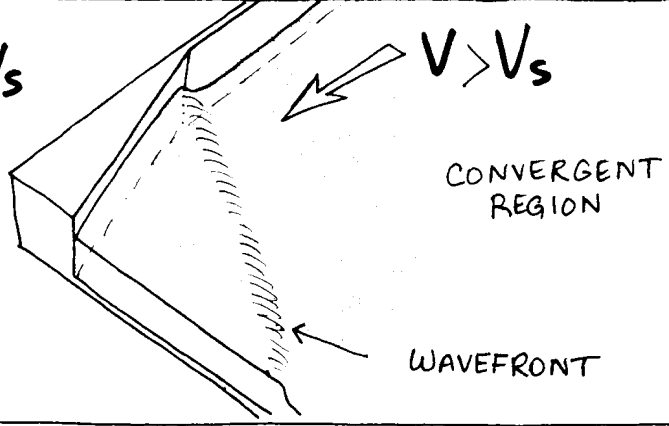
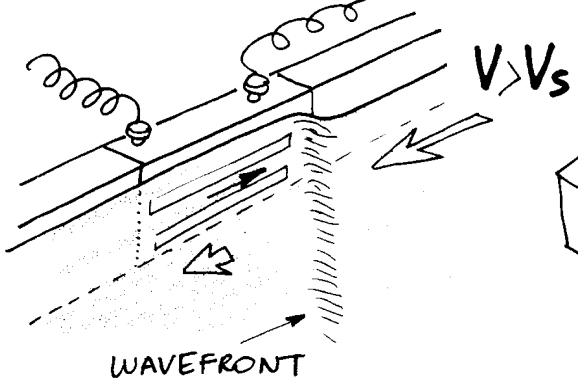
OH YES, LENNY - YOU'LL SEE. YOU AGREE THAT WHEN  $V > V_s$ , CHANGES IN DIRECTION OF A WALL CREATE EITHER A COMPRESSION OR AN EXPANSION. NOW, LOOK, THE MAGNETOHYDRODYNAMIC SYSTEM CREATES ABSOLUTELY IDENTICAL EFFECTS!

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

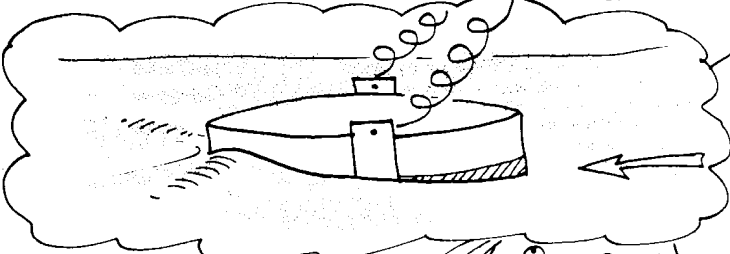


SO IT OUGHT TO BE POSSIBLE TO ARRANGE FOR THE MUTUAL ANNIHILATION OF THE PHENOMENA OF COMPRESSION AND EXPANSION BY CANCELLING THOSE OF "NATURAL" ORIGIN - DUE TO THE WALLS - AGAINST LAPLACE FORCES OF "ARTIFICIAL" ORIGIN.



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 REINFORCED.

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....

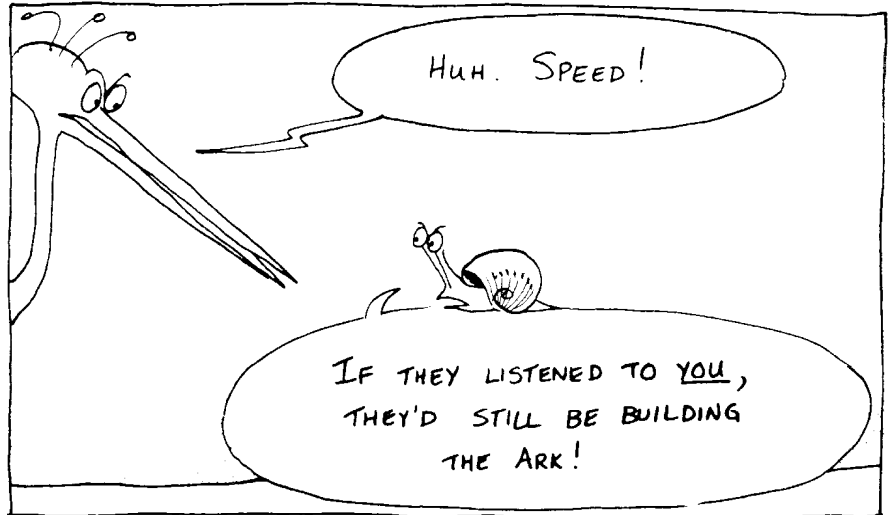
THAT'S RIGHT! SORT IT ALL OUT SO THAT YOU LEAVE THE FLUID IN THE STATE IN WHICH YOU WOULD WISH TO FIND IT... NO STERN WAVE!

BLOOMIN' MARVELOUS. TWENNY TESLAS WOLF O' MAGNETIZATION, AN' ARCHIE'S KERNOO SKIMS FRU THE WATER WIVAHT WAVEFRONTS AN' WIVAHT ANY TURBULENCE. NO DAMAGE TER LANDIN' STAGES. WOT NEXT?

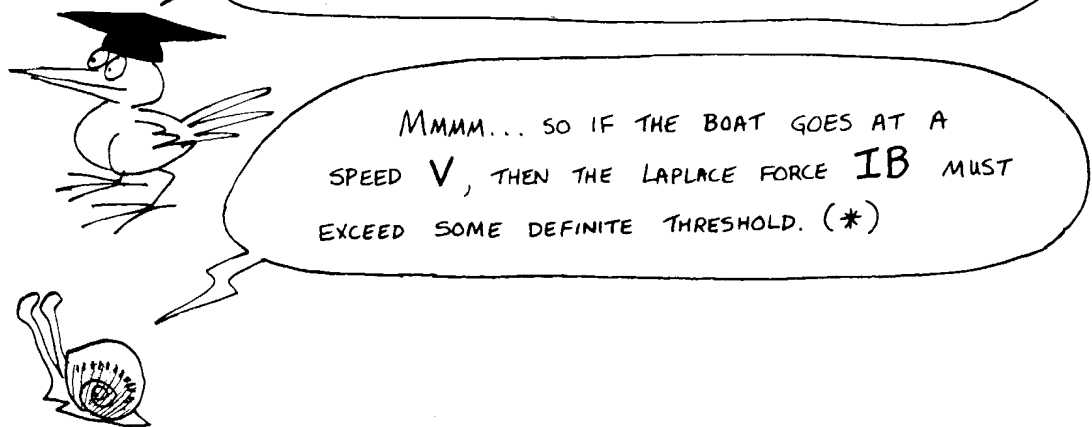
WOULDN'T IT BE EASIER JUST TO STAY FAR ENOUGH OUT TO SEA? DON'T YOU ALL HAVE MORE IMPORTANT THINGS TO DO?



I DON'T AGREE. I THINK WE OUGHT TO TAKE A GOOD LOOK AT ARCHIE'S IDEA, ESPECIALLY THE PARIETAL ACCELERATOR. ALL BOATS SUFFER A LOT FROM HYDRODYNAMIC DRAG - RESISTANCE TO FORWARD MOTION DUE TO FRICTION OF THE WATER AGAINST THE HULL. NOW THE PRESENCE OF WAVEFRONTS ALTERS THE PRESSURE DISTRIBUTION OVER THE CONTOUR OF THE HULL, LEADING TO A WAVE TRAIN IN ITS WAKE, WHICH GROWS RAPIDLY WITH THE SPEED AND THAT MUST BE THE MAIN FACTOR LIMITING THE SPEED AT WHICH THE BOAT CAN TRAVEL.

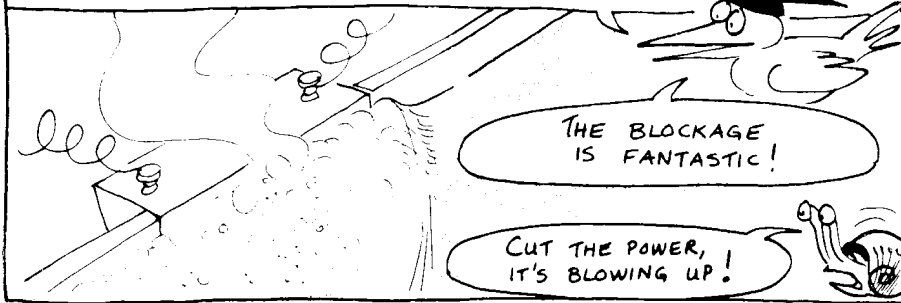


WE KNOW ROUGHLY HOW MUCH ENERGY MUST BE BROUGHT INTO PLAY TO SUPPRESS WAVEFRONTS. (\*) THE WORK DONE BY THE LAPLACE FORCES MUST BE AT LEAST THE INCIDENT KINETIC ENERGY OF THE FLUID.

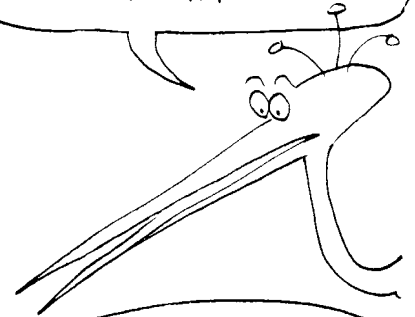


(\*) SEE APPENDIX B (PAGE 71)

IT'S BEST TO MAKE THE MAGNETIC FIELD  $B$  AS LARGE AS POSSIBLE. IF YOU HAVE  $B$  SMALL AND COMPENSATE BY MAKING  $I$  LARGE, THEN FIRST THE EFFICIENCY IS LOW, AND SECOND, ELECTROLYSIS WILL OCCUR, GIVING OFF A LOT OF GASES.

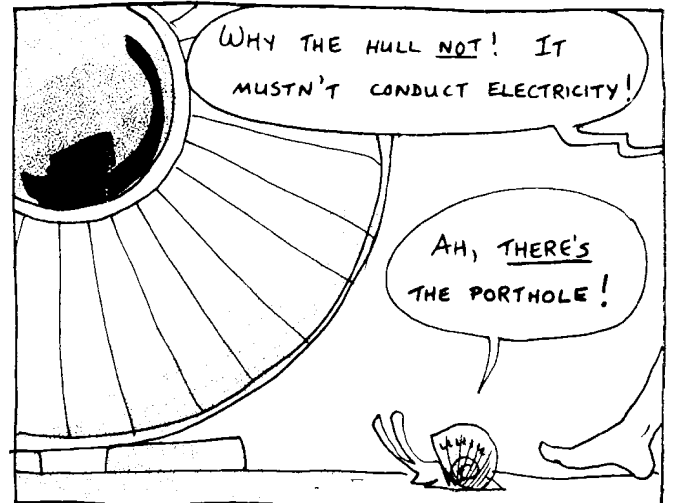
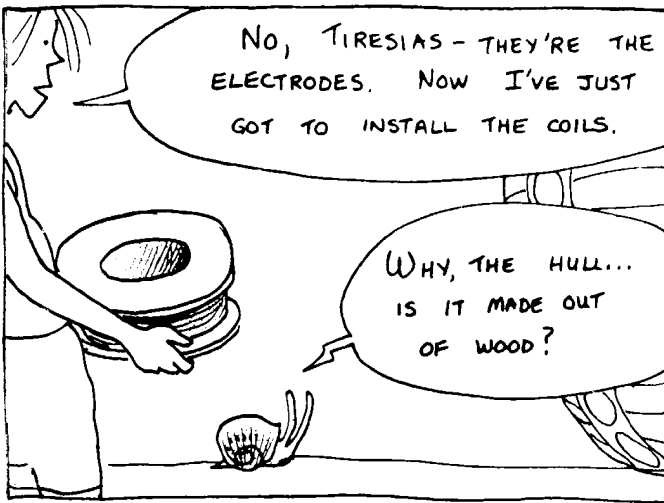
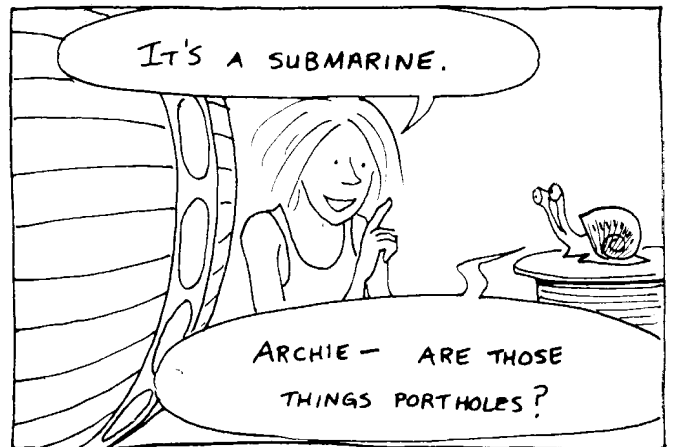


DON'T YOU FEEL THAT ALL THIS... ER... ELECTROMAGNETIC PROPULSION IS JUST A LITTLE BIT ADVANCED FOR THE CURRENT STATE OF TECHNOLOGY?

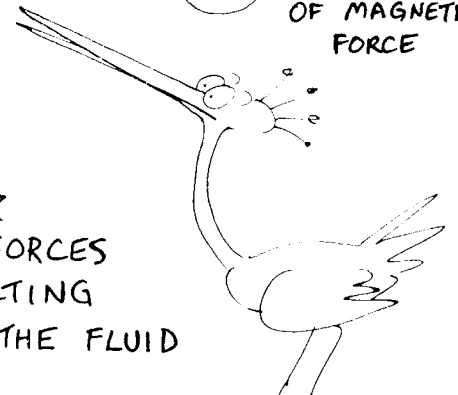
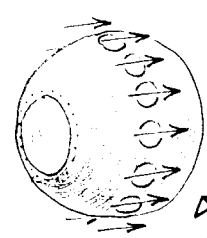
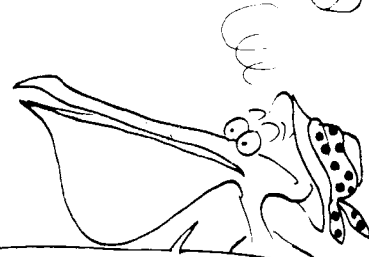
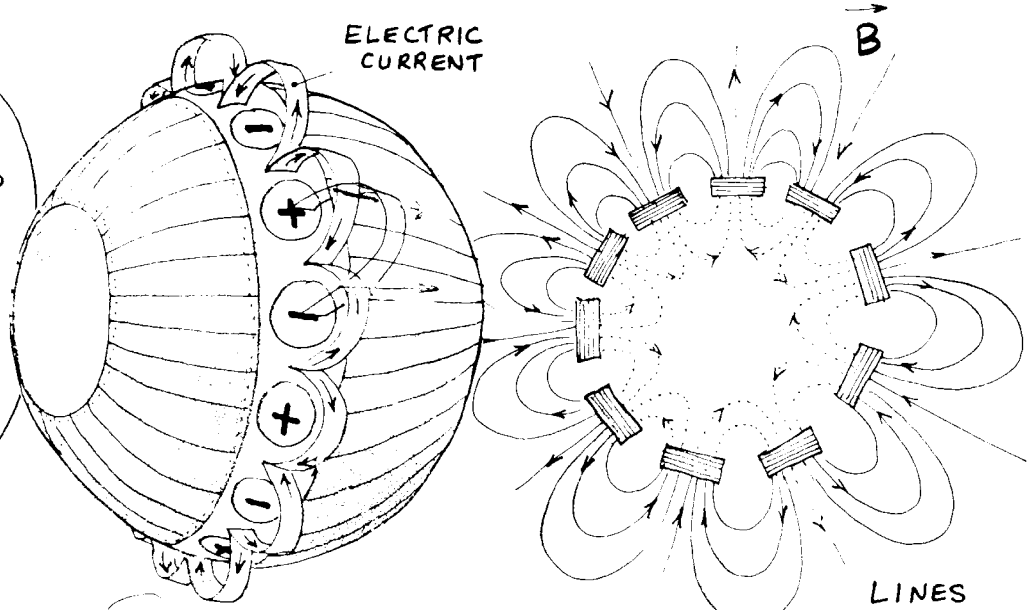


WE JUST NEED TO INNOVATE, THAT'S ALL!

# THE SCREWLESS SUBMARINE

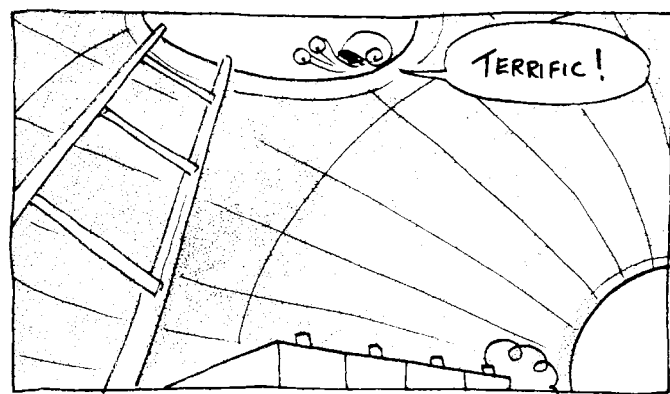


SEE, IF YOU APPLY THE RIGHT-HAND RULE, YOU CAN WORK OUT THAT THE DEVICE PRODUCES A FIELD OF LAPLACE FORCES SUITABLE FOR PROPULSION.



YER'LL NEVER GET ME IN ONE O' THEM FINGS!

FORCES ACTING ON THE FLUID

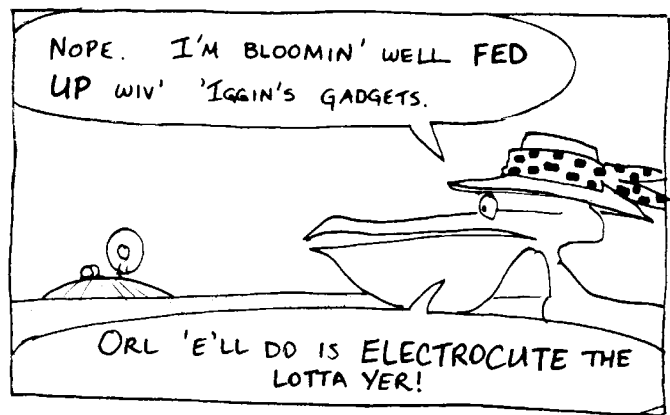


TERRIFIC!



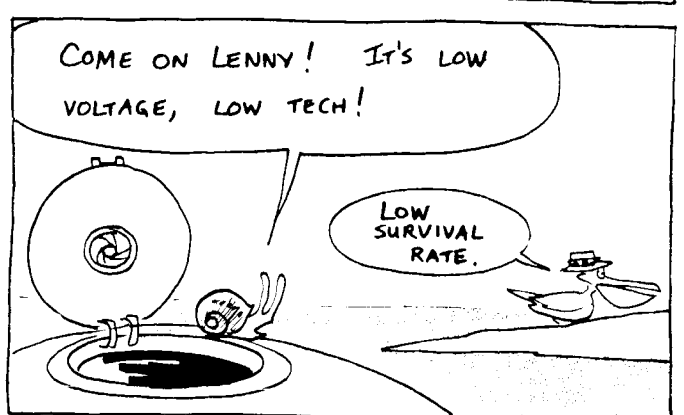
COME ON, LENNY! STOP MAKING FACES!

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.

I DUNNO 'OW YOU FEEL ABAHT IT... BUT TER ME, IT'S ORL JUST A TINY BIT DUBIOUS ....

ME TOO.

HOW DO YOU STEER IT?

SIMPLE: YOU FIDDLE WITH THE INTENSITIES OF THE ELECTRODES.

TURN...

... STOP...

... OR GO INTO REVERSE.

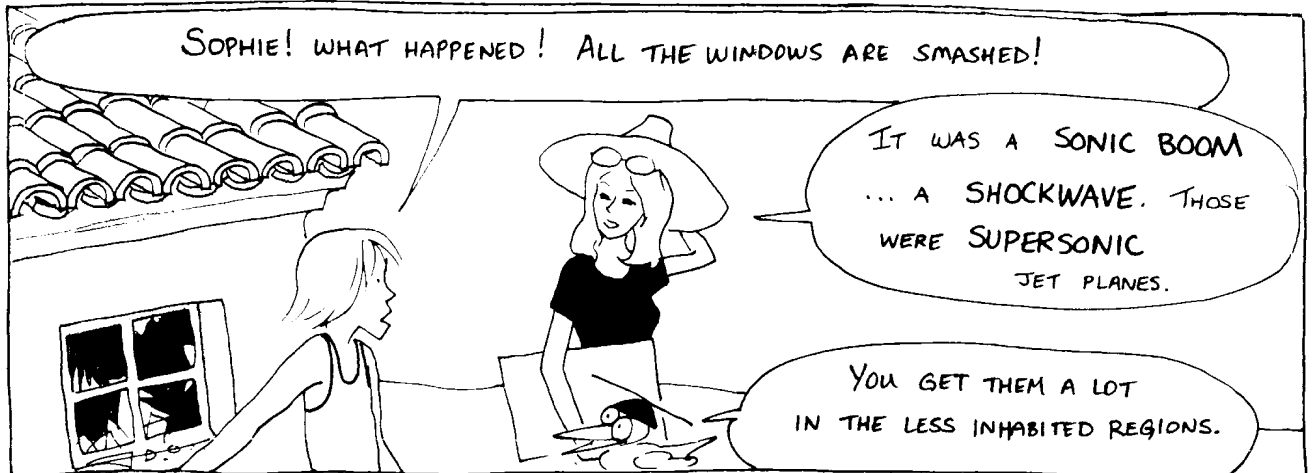
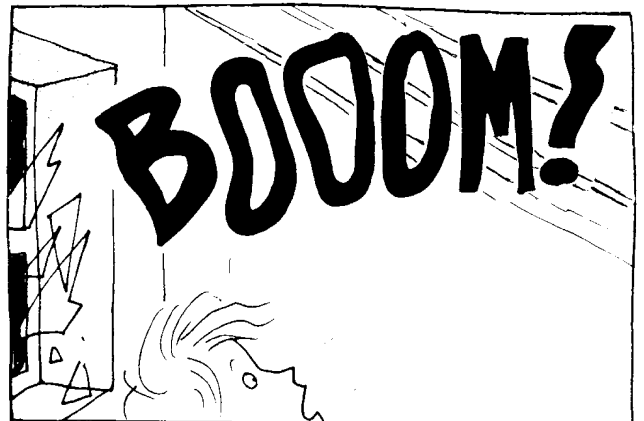
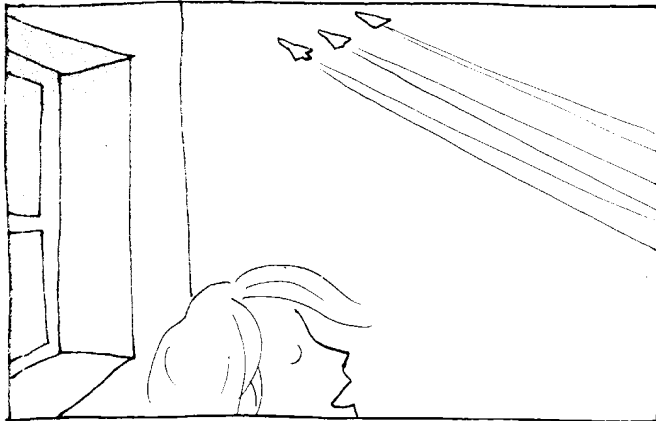
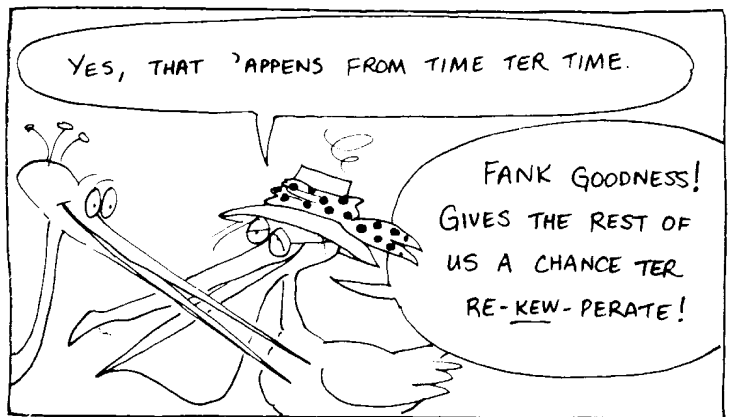
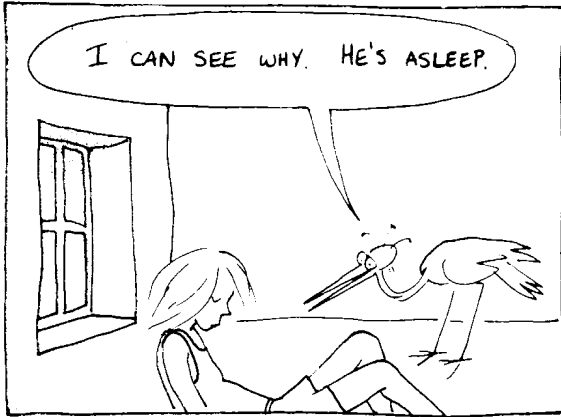
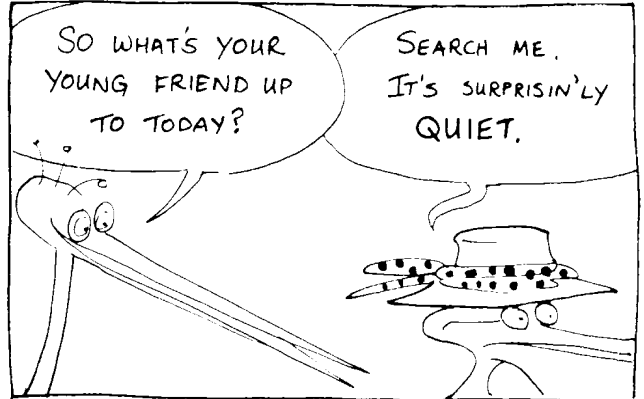
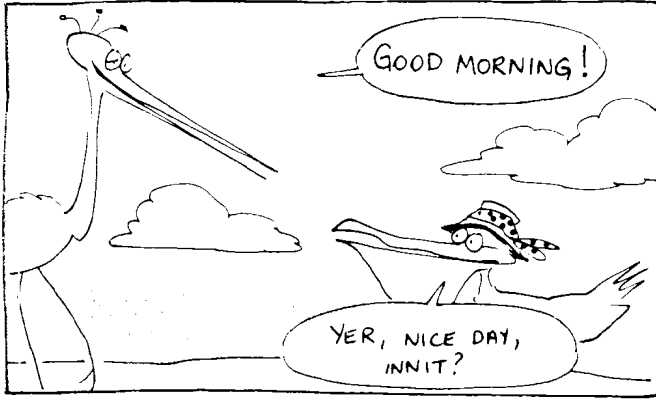
AN MHD SUBMARINE COULD BE VERY QUICK AND COMPLETELY SILENT.

DRAT!

THAT'S HOW IT GOES, MY DEAR LENNY. WHEN WE GET EFFECTIVE SUPERCONDUCTING MAGNETS (\*) AND ULTRA-EFFICIENT ELECTRICAL GENERATORS, BOATS WILL STOP MAKING WAVES, AND SUBMARINES WILL BLOW BUBBLES.

(\*) 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.



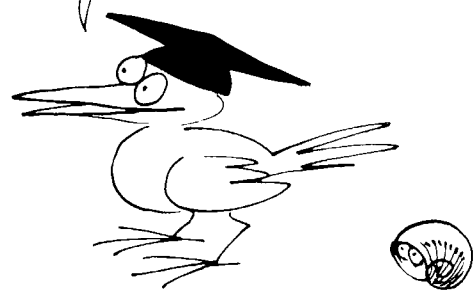
YOU CAN COMPARE THE MOTION OF MOLECULES TO A LOT OF BLUNDFOLDED PEDESTRIANS, WANDERING ABOUT AT A SPEED  $V_s$  IN A TOTALLY DISORDERED FASHION, IN ONE PLACE, CONTINUALLY BUMPING INTO EACH OTHER (MOLECULAR COLLISIONS). AN OBJECT PENETRATING A GAS IS SIMILAR TO A BUS, RUNNING INTO THE CROWD AT A SPEED  $V$ . 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.

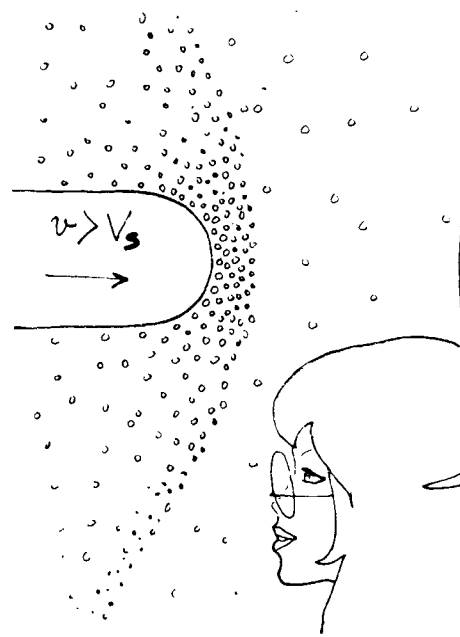
BUT WHAT HAPPENS WHEN  $V$  IS GREATER THAN  $V_s$ ?



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

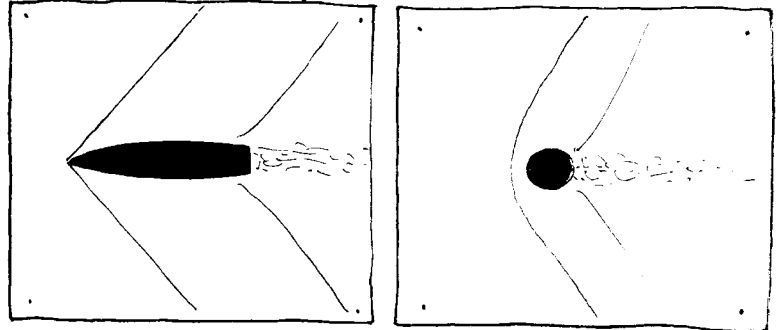


THIS PHENOMENON IS CALLED A SHOCKWAVE. HERE SOUND WAVES REPLACE SURFACE WAVES, OTHERWISE IT'S JUST THE SAME AS FOR A BOW WAVE. FRONTS OF DENSITY, PRESSURE, AND TEMPERATURE ARE INEVITABLY FORMED. THE SHOCKWAVE OCCURS WHEN THE SPEED  $V$  OF THE FLOW IS GREATER THAN THE SPEED OF SOUND  $V_s$ .



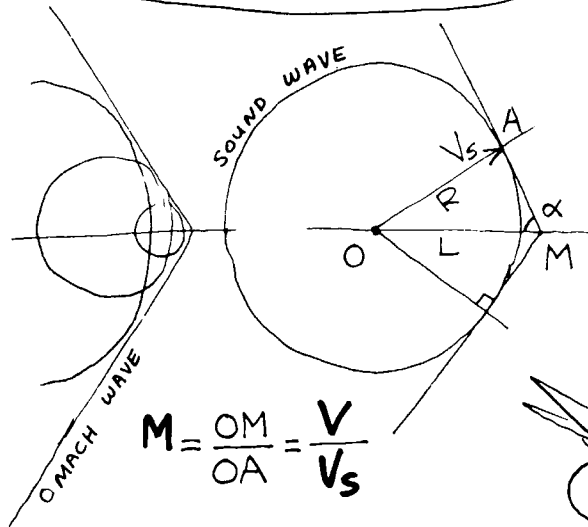
YOU MEAN TO SAY THAT EVERY TIME THOSE HOTSHOTS AT THE AIR FORCE BASE DECIDE TO AMUSE THEMSELVES WITH SOME HIGH-SPEED AEROBATICS, I HAVE TO LUG A HEAP OF REPLACEMENT WINDOWS AROUND THE HOUSE!

YEAH, THAT FIGURES!



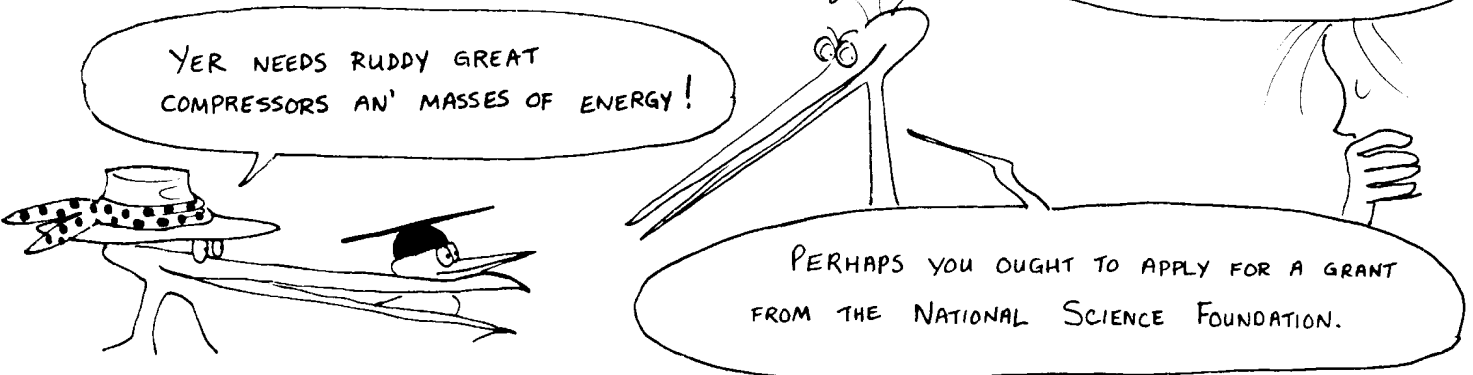
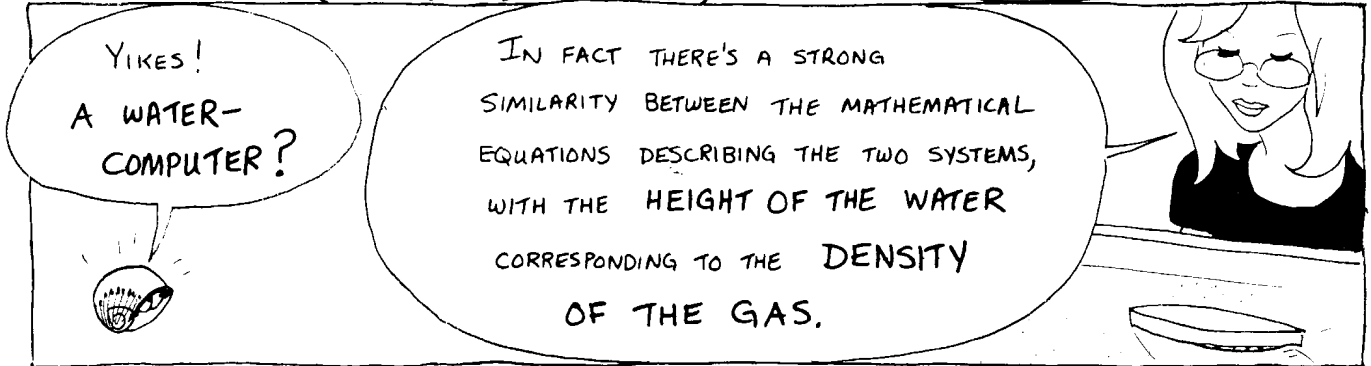
SO EVERY OBJECT TRAVELING AT A SUPERSONIC SPEED (FASTER THAN SOUND) WILL HAVE A **FRONTAL** SHOCKWAVE AND A **REAR** SHOCKWAVE. ON THE LEFT IS A BULLET, ON THE RIGHT A SPHERE.

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**. (\*)



(\*) SEE APPENDIX A (PAGE 91).

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.



# 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?

COMPRESSION

EXPANSION

$V > V_s$

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

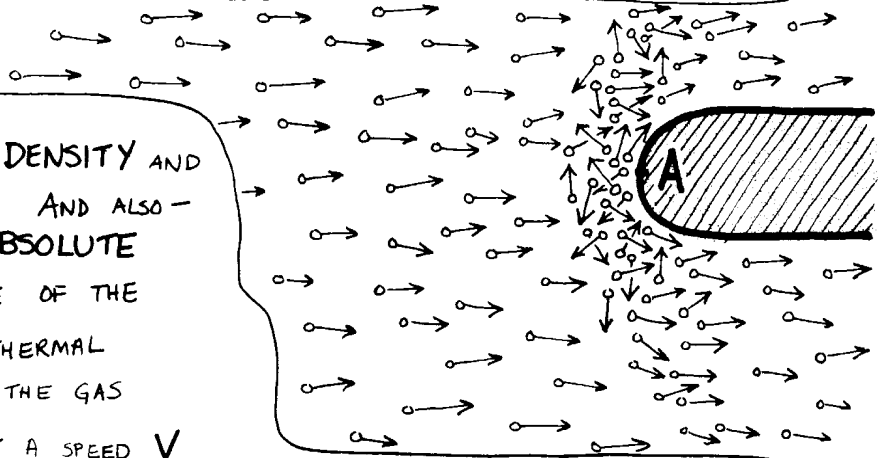
IT'S NOISY, IT'S USELESS, AND IT WASTES ENERGY.

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!



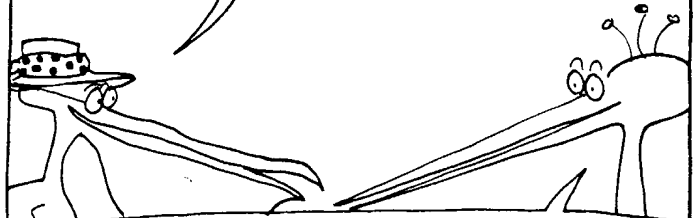
ACROSS A SHOCKWAVE, THE DENSITY AND PRESSURE INCREASE DRAMMATICALLY. AND ALSO - THE TEMPERATURE. THE ABSOLUTE TEMPERATURE IS A MEASURE OF THE KINETIC ENERGY  $\frac{1}{2}mv^2$  OF THERMAL AGITATION OF MOLECULES. IF THE GAS "COLLIDES" WITH AN OBJECT AT A SPEED  $V$ , THEN AT THE STATIONARY POINT A (WHERE 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?

←  $V > V_s$

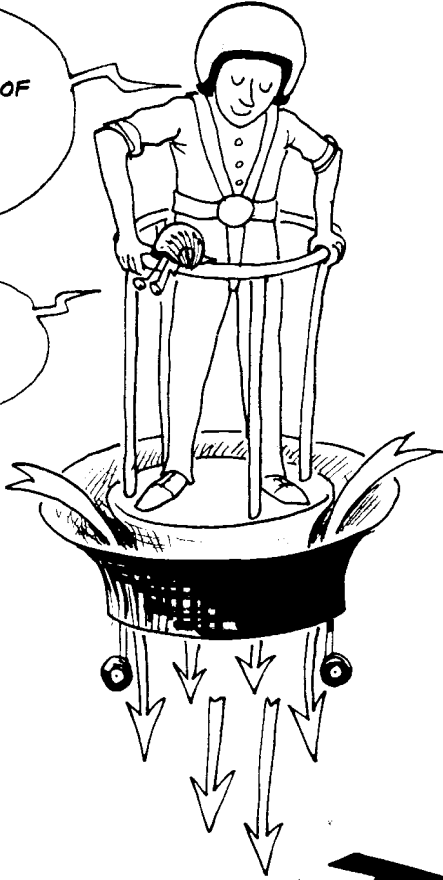
IF THE HYDRAULIC ANALOGY IS ANYTHING TO GO BY, IT LOOKS AS IF THERE ARE THREE METHODS OF FLYING.

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.

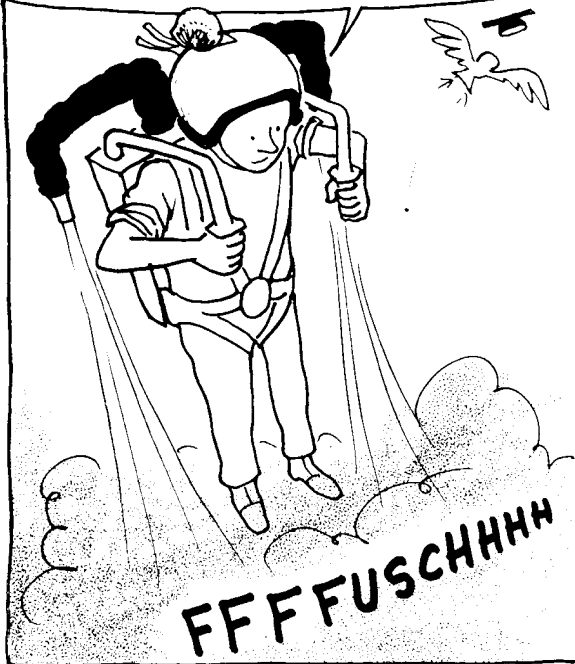


MORONIC MOLLUSC!  
A ROTOR IS JUST A REVOLVING AIRFOIL.

SILLY ME.

HERE'S HOW TO OBSERVE THE INDUCED VELOCITY.

SECOND SYSTEM: ACCELERATE A GAS THAT YOU PRODUCE YOURSELF.



FFFUSCHHHH

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.

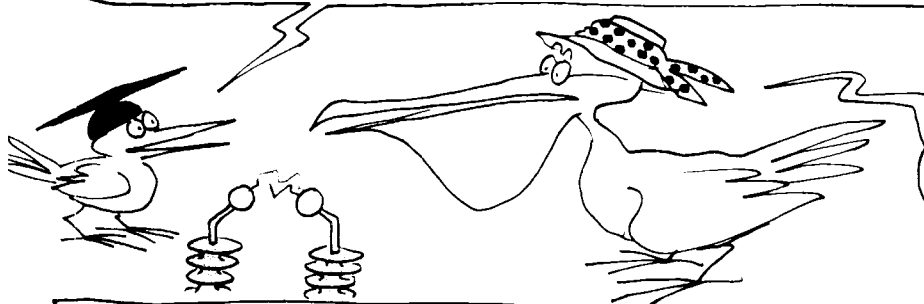
WHAT'S UP WITH YOU?

ARCHIE'S GOT SOME CRAZY IDEA IN 'IS 'EAD... ABAHT FLYIN' WIV H'ELECTRICITY.

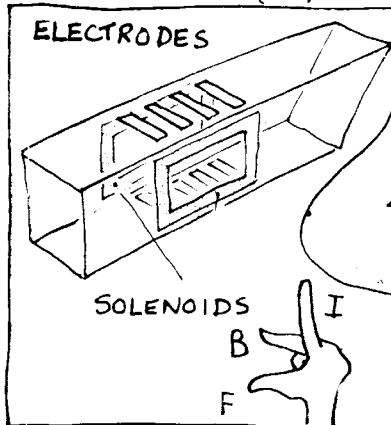
I POINTED OUT TO LENNY MYSELF, JUST NOW, THAT IT'S IMPOSSIBLE, BECAUSE AIR WON'T CONDUCT ELECTRICITY.

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!



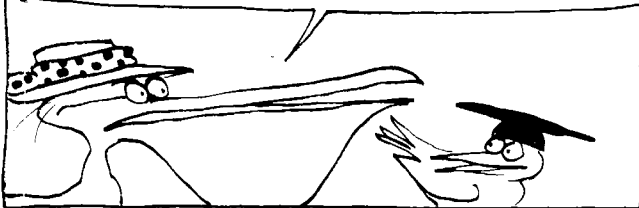
SO WHEN'S THE ELECTRIC CONCORDE COMIN', EH?



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 BUNKIN' 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.

THUNDER?

I 'OPE YER GOT A REAL BANG OUTTA THAT!

HMMM? WHAT?

THUNDER.



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!

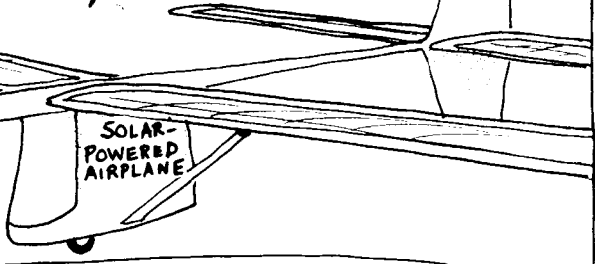
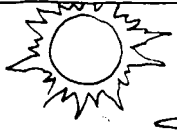
PROCEEDINGS  
OF THE  
NATIONAL  
ACADEMY  
OF  
SCIENCES

D'YER REALIZE 'OW COMPLICATED IT'D 'AVE TER BE? YER'D 'AVE  
TER 'AVE A COOLIN' SYSTEM FER THE SOOPA CONDUCTORS, 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.

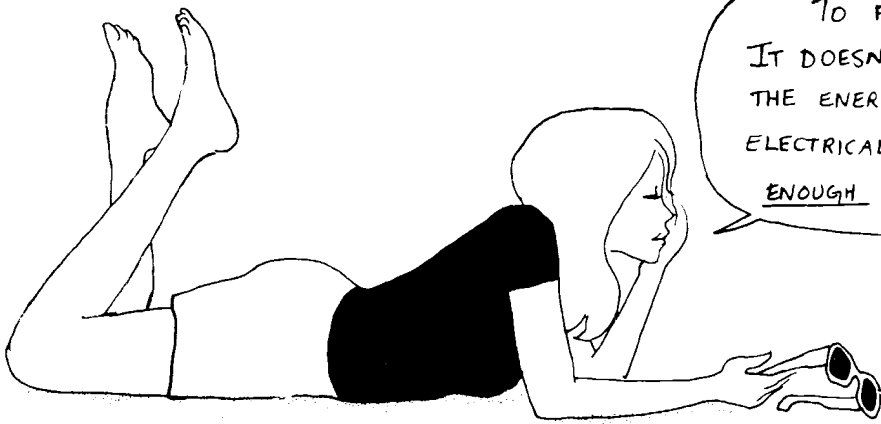
OH YEAH? SO WHAT  
MAKES THAT FLY?



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

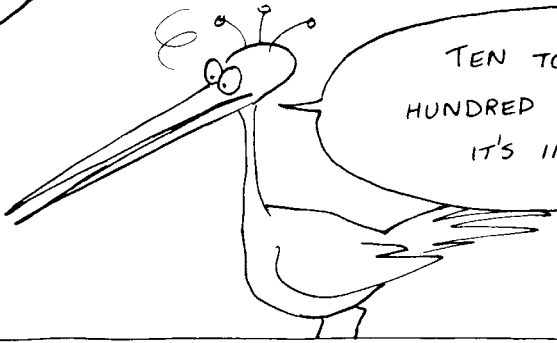
5000 WATTS PER KILOGRAM

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!

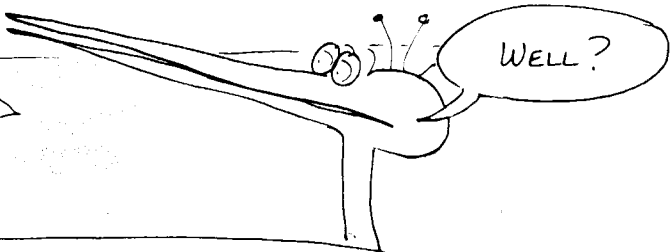


TEN TONS FOR A HUNDRED MEGAWATTS - IT'S IMPOSSIBLE!

Well?  
Sophie?

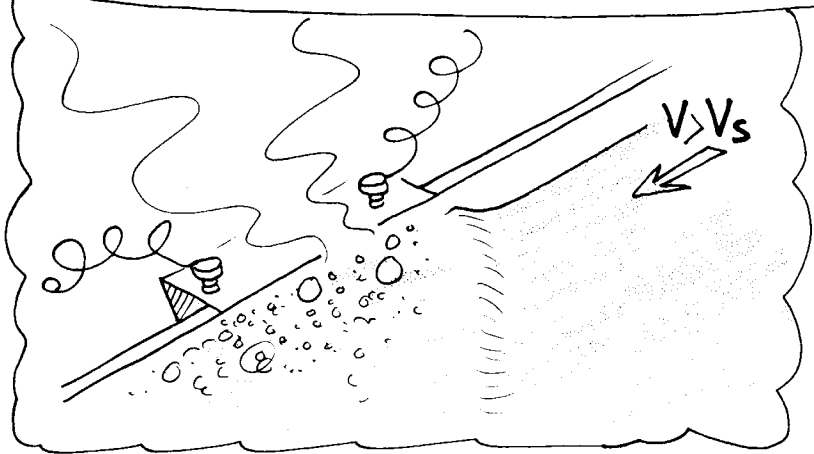


CONFOUND THAT HIGGINS! IT'S FINALLY BEGINNING TO LOOK AS IF YOU'VE GOT TO EXTEND TO GASES THE IDEA WE REACHED FOR FLOWS OF A LIQUID WITH A FREE SURFACE: THE INTERACTION CRITERION AND ITS EFFECTS ON MHD EFFICIENCY. THERE MUST BE A SNAG SOMEWHERE - I WONDER WHAT IT IS?



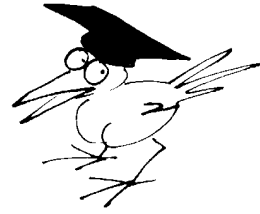
Well?

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

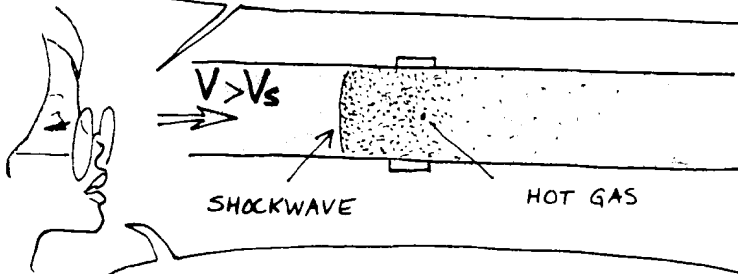


# THERMAL BLOCKAGE

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.

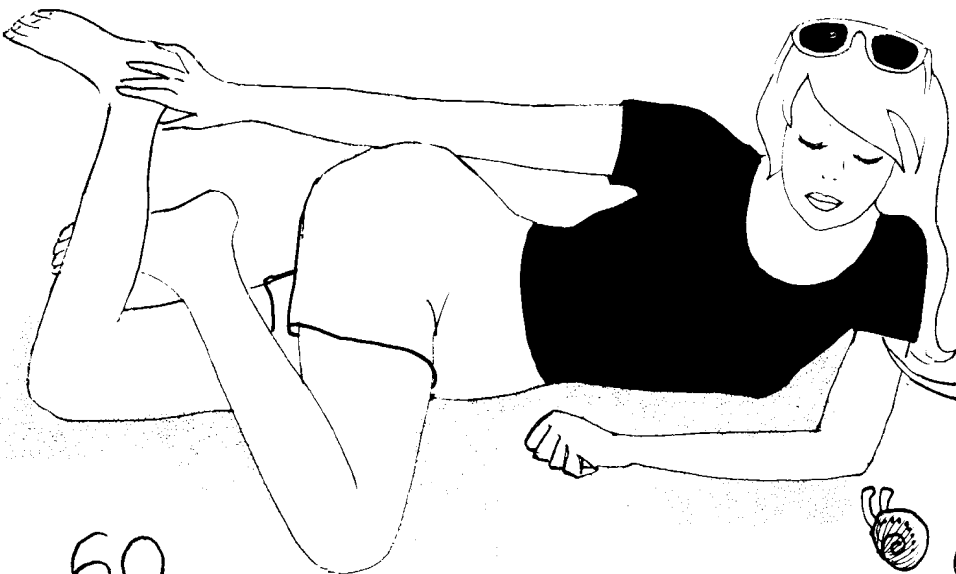


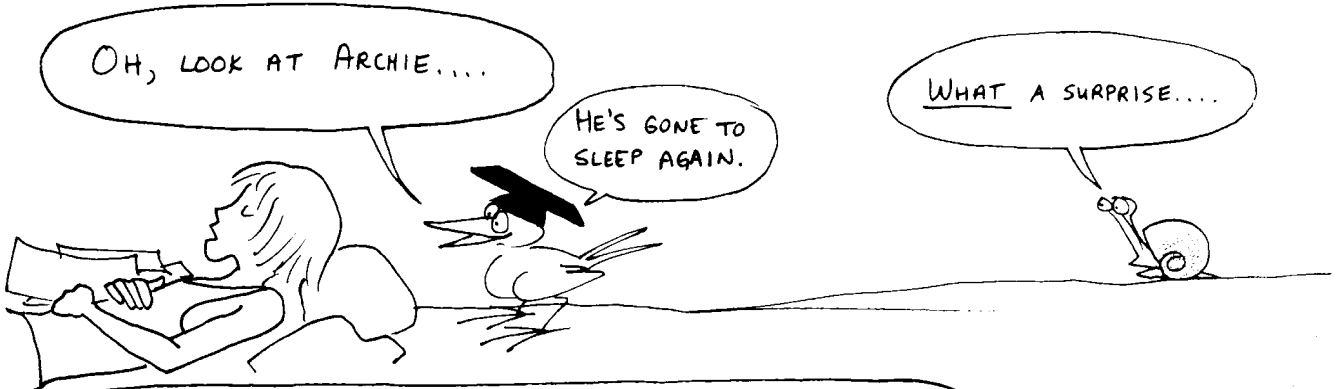
IT'S A THERMAL BLOCKAGE.

SO ARCHIE'S EXPERIMENT IS DOOMED TO FAILURE?



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.



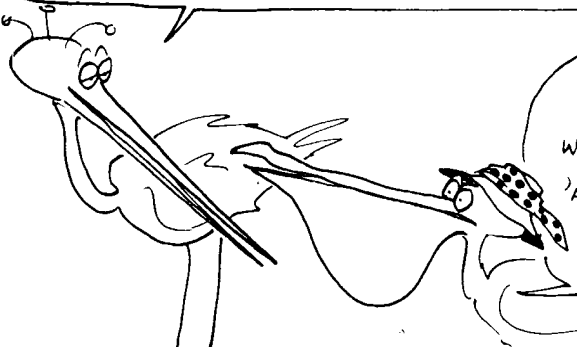


OH, LOOK AT ARCHIE....

HE'S GONE TO SLEEP AGAIN.

WHAT A SURPRISE....

WHAT DO YOU MAKE OF ALL THAT?

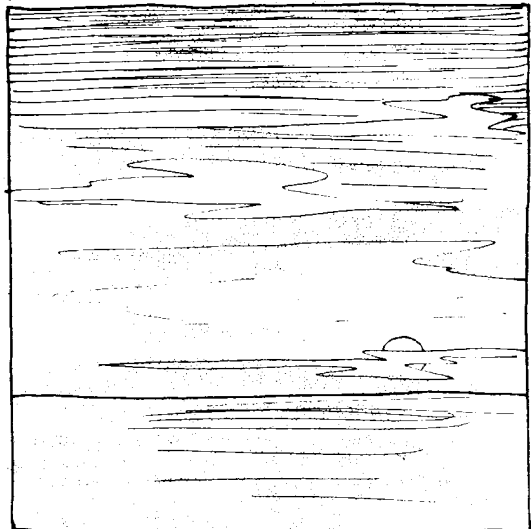


H' INASMUCH AS THESE 'ERE MHD H'AERODYNE WOTSITS CORRESPOND TO TECHNOLOGY WOT MIGHT 'APPEN IN THE NEX' CENCHERY - IT'S QUESTIONABLE WEVVER IT'S WORF THE BLEEDIN' CANDLE, INNIT.

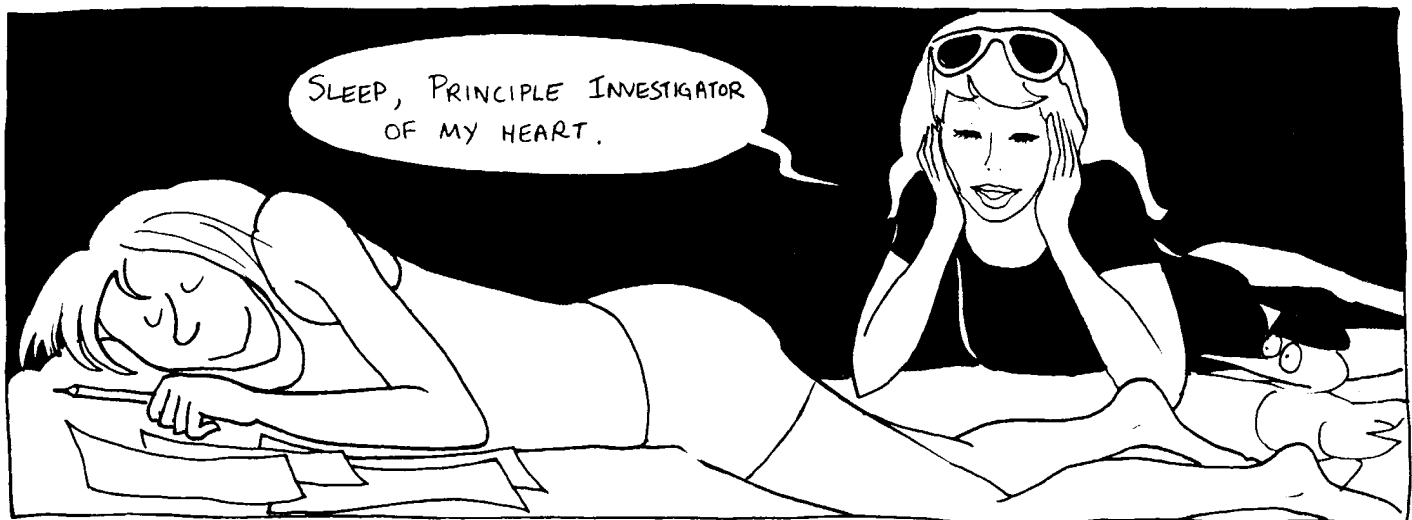


BUT THERE MIGHT BE SOME INTEREST FOR BASIC SCIENCE?

YUR, SURE, BASIC SCIENCE....



HEAVENS... WHAT A DAY!



SLEEP, PRINCIPLE INVESTIGATOR OF MY HEART.

# ARCHIBALD'S DREAM

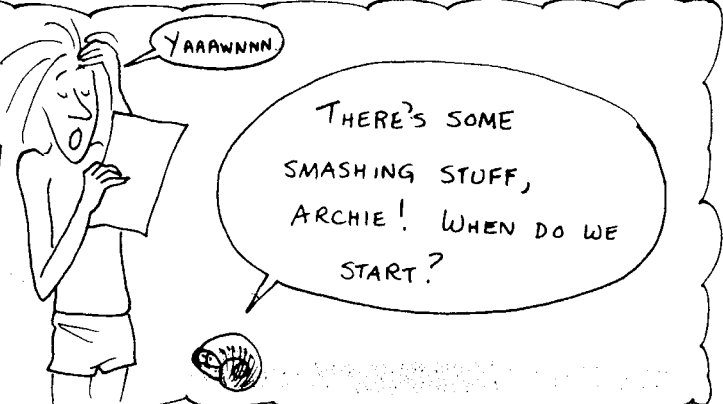
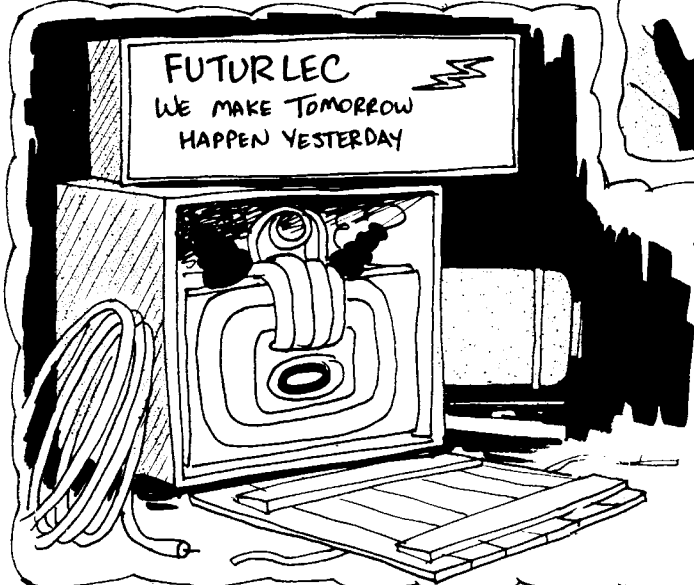


UMPPH... ER... YEAH....

MR. HIGGINS? YOU ORDERED  
A TWO-HUNDRED-MEGAWATT ELECTRICAL  
GENERATOR, A TEN-MEGAWATT MICROWAVE  
SOURCE, A REEL OF SUPERCONDUCTING WIRE,  
TOTAL WEIGHT TWENTY TONS...?



SIGN HERE,  
PLEASE!



YAAAWNNN

THERE'S SOME  
SMASHING STUFF,  
ARCHIE! WHEN DO WE  
START?

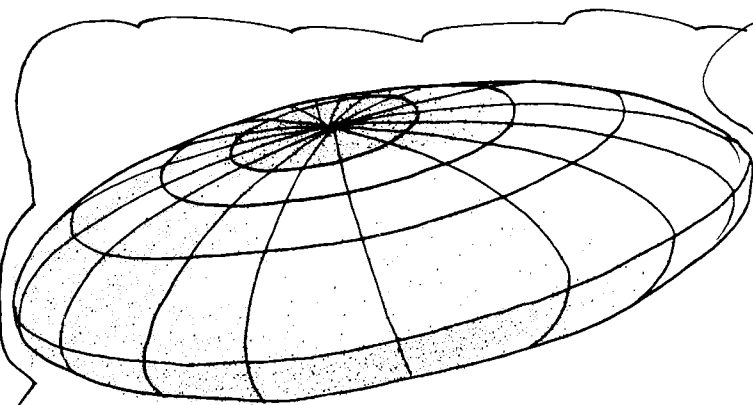


THAT WAS A WEIRD TRUCK HE HAD,  
TIRESIAS. DID YOU SEE IT?



NEVER SEEN ANYTHING  
LIKE IT! OH, WELL....

WE GO FOR IT?  
WE GO FOR IT?



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.

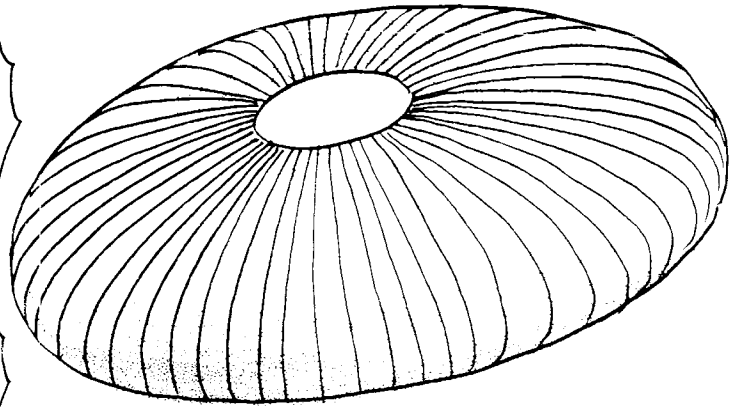
THE WIRES WILL BE COOLED TO VERY LOW TEMPERATURE WITH LIQUID HELIUM.

⊙ 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 2 MILLIMETERS.

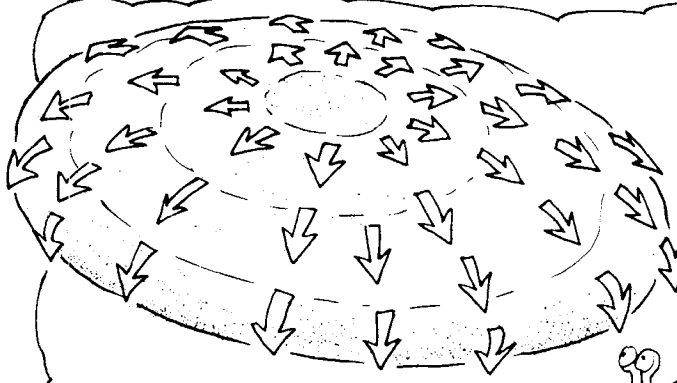
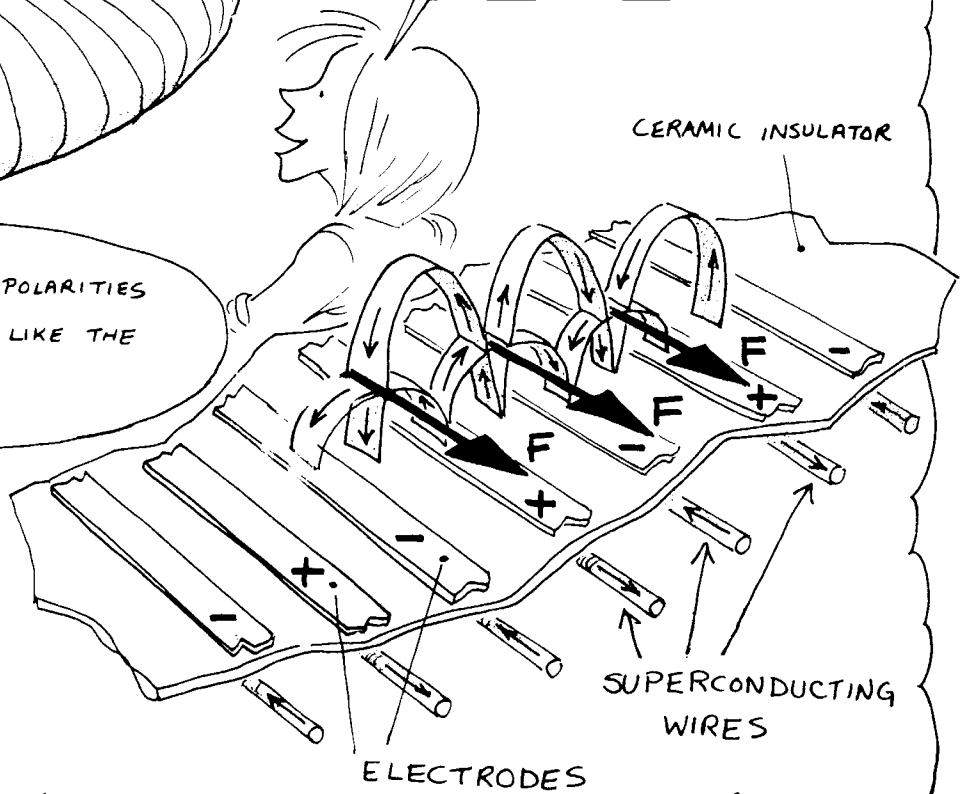
THE WIRES WILL FOLLOW THE MERIDIANS OF THE VEHICLE.

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.

AND YOU ALTERNATE THE POLARITIES OF THE ELECTRODES — JUST LIKE THE PARIETAL ACCELERATOR



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.

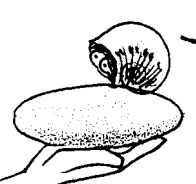
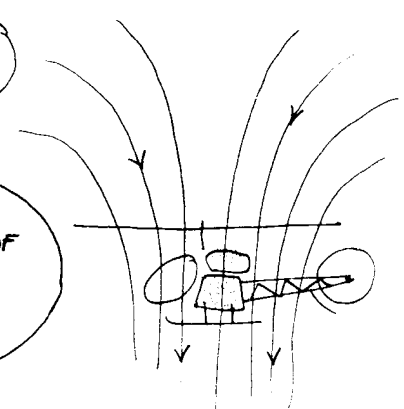
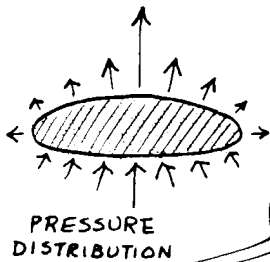
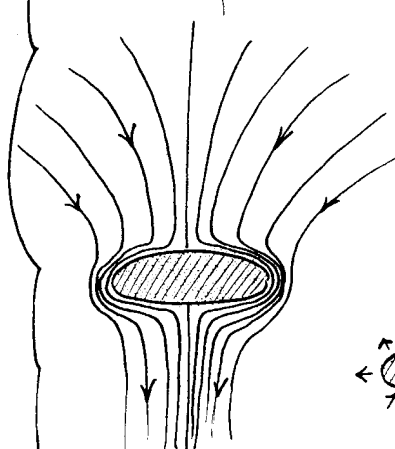
THIRD, THE ACTION TAKES PLACE IN A THIN LAYER, CONCENTRATING THE IONIZATION, THE FORCE.

AND HERE'S THE GASEOUS FLOW THAT RESULTS.

IT'S LIKE A SORT OF ELECTROMAGNETIC HELICOPTER.

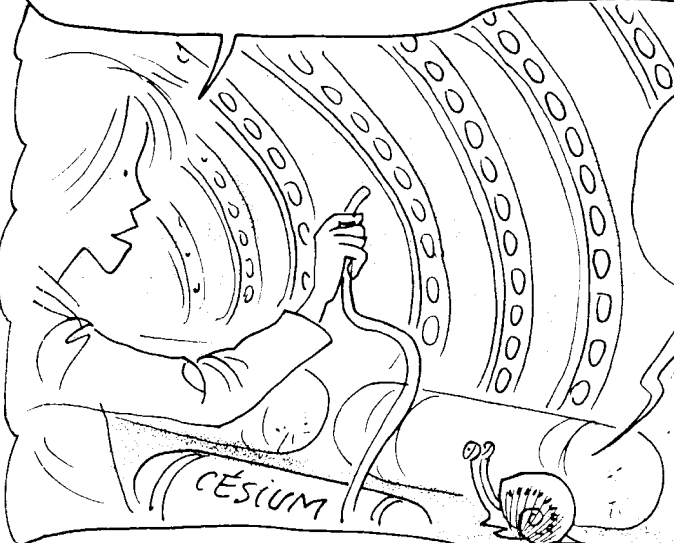
IT JUST REMAINS TO PRODUCE ENOUGH IONIZATION, THAT IS, ENOUGH FREE ELECTRONS IN THE LAYER OF GAS.

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

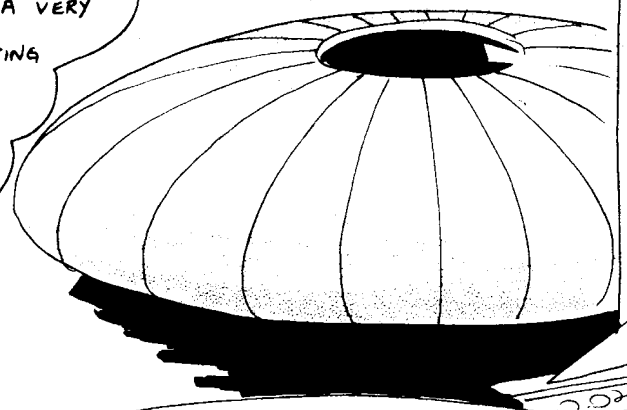
THE COMPONENT OF THE AIR THAT PROVIDES FREE ELECTRONS ISN'T OXYGEN OR NITROGEN, BUT NITROUS OXIDE (NO). BUT THE SIMPLEST SOLUTION IS TO ENRICH THE AIR WITH A SUBSTANCE THAT GIVES OFF PLENTY OF FREE ELECTRONS, SUCH AS CESIUM OR SODIUM.



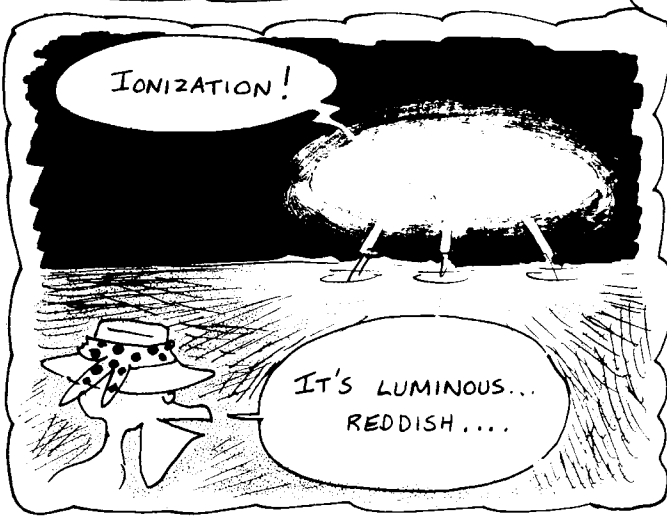
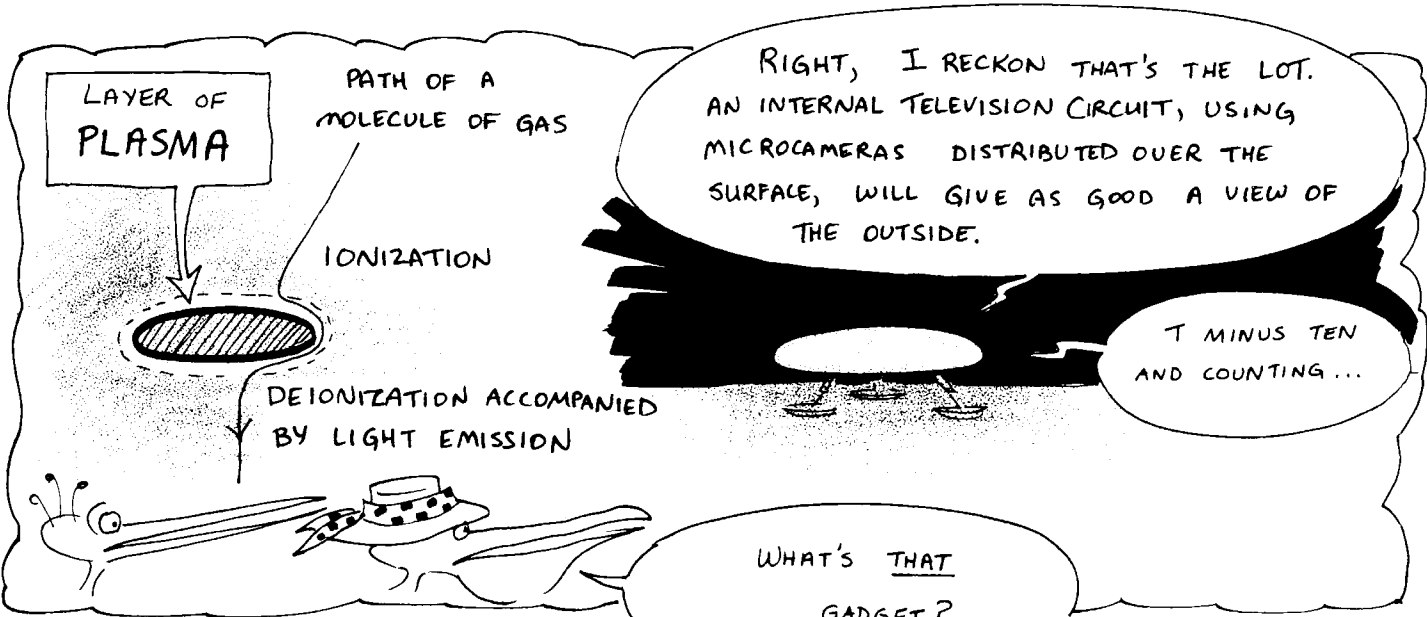
SO WE BORE PORES THROUGH THE CERAMIC COVERING, AND EMIT SMALL QUANTITIES OF CESIUM VAPOR THROUGH THEM DURING FLIGHT.



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.



CRAZY... IT FLIES  
JUST LIKE A HELICOPTER.

!?

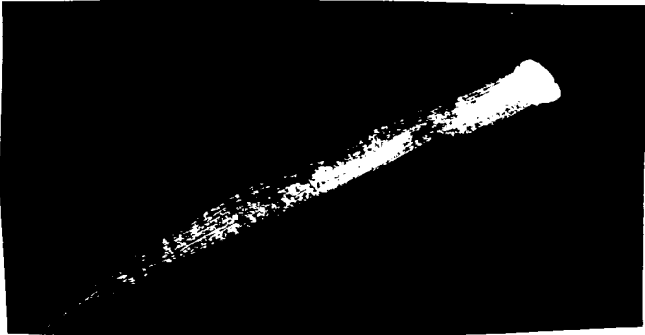
SOPHIE!

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...

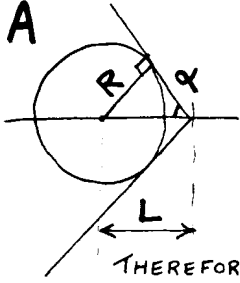


THE SILENCE BARRIER

THE  
END

# SCIENTIFIC APPENDICES

A



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

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

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  $1 \text{ A/cm}^2$  ( $10^4 \text{ A/m}^2$ ). SUPPOSE  $V = 8 \text{ CM/SEC}$ .  $\leftarrow 2 \text{ MM}$  ASSUME THE CYLINDER GOES  $8 \text{ MM}$  ( $8 \times 10^{-3} \text{ M}$ ), WITH AN INTERACTION LENGTH EQUAL TO THE SIZE OF THE ELECTRODE:  $2 \times 10^{-3} \text{ M}$ ; AND  $\rho = 10^3 \text{ KG/M}^3$ . IF  $B = 1 \text{ TESLA}$  ( $10,000 \text{ GAUSS}$ ) 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  $10^{-3} \text{ KG}$  OR  $10^{-2} \text{ NEWTONS}$ . IT TRAVELS AT  $0.1 \text{ M/SEC}$ , CORRESPONDING TO A POWER OF  $10^{-3} \text{ WATTS}$ . 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  $\frac{JBL}{t}$  IS THE SPEED  $V$ . MOREOVER, THE POWER DISSIPATED BY THE JOULE EFFECT IS  $J^2/\sigma$ , WHERE  $\sigma$  IS THE ELECTRICAL CONDUCTIVITY.

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

WITH  $\sigma = 10 \text{ MHOS/M}$

$B = 25 \text{ TESLAS}$

$V = 20 \text{ M/SEC}$

$J = 10^4 \text{ A/M}^2$

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  $\rho$  IS THE DENSITY OF THE AIR ( $1.3 \text{ KG/M}^3$ ) AND  $V$  IS THE SPEED OF THE OBJECT. FOR A FRONTAL AREA OF  $1 \text{ M}^2$ , THE POWER  $P$  LOST IN THE WAVE TRAIN WILL BE  $\frac{1}{2} \rho V^3$ .

IF  $V = 600 \text{ M/S}$   $P = 200 \text{ MW}$   
IF  $V = 1500 \text{ M/S}$   $P = 2000 \text{ MW}$

E

THE POWER ASSOCIATED WITH MHD ACCELERATION IS **JBV**. WITH  $J = 10^4 \text{ A/M}^2$ ,  $B = 4 \text{ TESLAS}$ ,  $V = 1000 \text{ M/SEC}$ , WE HAVE  $JBV = 40 \text{ MW/M}^3$ . IF THE ELECTRICAL CONDUCTIVITY OF THE AIR (AWAY FROM EQUILIBRIUM) REACHES  $10 \text{ MHOS/M}$ , THAT OF SALT WATER, THEN THE HEAT  $J^2/\sigma$  PRODUCED BY THE JOULE EFFECT, CORRESPONDS TO A POWER OF  $10 \text{ MW/M}^3$ . IT'S ATTAINABLE. IT WOULD BE BEST TO WORK WITH  $B$  LARGE ( $20 \text{ TESLAS}$ ) AND TO INCREASE ARTIFICIALLY THE CONDUCTIVITY  $\sigma$  (BY EMITTING ALKALI THROUGH A POROUS WALL OR VIA THE ACTION OF MICROWAVES).

