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TABLE OF CONTENTS

		Page
1.	Introduction	1
2.	The Tools Used in this Investigation	3
3.	A Closer View of the Experiment	4
4.	Recommendations and Requirements	7
5.	Areas for Further Investigation	8
6.	Summary	9

Appendix 1. Cloud Droplet Coalescence Experiments in Orbit

Appendix 2. Modeling of Cloud Drop Collisions with Low Gravity

Appendix 3. Interim Final Report, 15 January 1976

Appendix 4. Monthly Progress Report, 17 February 1976

Appendix 5. Monthly Progress Report, 15 March 1976

Appendix 6. Monthly Progress Report, 1 June 1976

Appendix 7. Monthly Progress Report, 1 July 1977

Appendix 8. Monthly Progress Report, 7 July 1977

Appendix 9. Monthly Progress Report, 15 March 1978

Appendix 10. Mini-Computer (MAC 16) Coding

1. INTRODUCTION

The availability of earth-orbiting laboratories makes possible experiments that would be difficult on earth. One area for which this is true is the study of cloud droplets. In nature, the collisions and coalescence of these droplets brings rain in warm clouds. In the laboratory, the small size of these droplets, say around 20 microns, makes them elusive objects for study. The slightest air current or electric charge sends them swirling about. Their rate of fall, say around 1 cm sec^{-1}, is fast enough to prevent more than hurried examination in a reasonably sized instrument. Under low gravity conditions the pace slows down. It becomes practical to do the experiment of placing droplet A above droplet B so that A overtakes and collides with B. In earth orbit there is a convenient source of low gravity generated by rotating the apparatus to give centrifugal force. It may be controlled by changing the rate of rotation or by moving away or towards the center of rotation. Another advantage is that one may use larger droplets. The Reynolds number of a falling droplet varies with the gravitational acceleration and with the cube of the droplet radius. Thus, in a gravitational field of 10^{-3}g one may model terrestrial conditions with droplets 10 times larger. These drops will fall only a tenth as fast as their earth-side analogs.

The interest in these drops arises because of the role they play in rain formation in warm clouds and in the formation of larger cloud drops able to play a role in ice and water collision processes to initiate precipitation in supercooled clouds . . . Appendix 1 describes the meteorological background of the experiment and Appendix 2 is the original conference paper on this subject.

This discussion relates to the work actually completed under this contract. Reference will be made to the Appendices for past project reports describing particular details of the work as they are discussed.

One basic design has been investigated in the project. The experimental chamber is basically a long tube rotated about an axis perpendicular to its length (See Appendix 3). Droplets are injected by some means such as a vibrating needle. The injection velocity is rapidly lost, leaving the droplets near a fixed point in the chamber. The conditions in the tube are controlled to prevent the droplets from evaporating appreciably during the experiment. Also condensation on the optics, etc. must be avoided. The droplets are injected near the center of rotation. Near this point droplet motion will be very slow, allowing time to examine and align the droplets. When the droplets have been positioned properly, the tube is shifted along its length to bring the droplets out to a fixed distance from the axis of rotation. Then the tube is shifted at a rate to counteract fall of the lighter droplet. This droplet sits at a fixed distance and feels a fixed gravity. The heavier droplet has been arranged so that it will pass near the other droplet for a collision or close encounter. The rotation and other motions of the apparatus are controlled using stepping motors. It is important that the control of these movements be done accurately and continually. This can only be done using a computer. In fact every effort should be made to do all control with a computer. The most an operator need do is provide a few measurements of droplet locations. There is no need to touch the droplets to move them about. By moving the mass of air in which they reside, the droplets may be manipulated. For example a cylinder may be inserted into the chamber to enclose the droplets. This may be done without creating enough turbulence to disturb the droplets. This "squirrel cage" can be rotated to realign the droplets within (See Appendix 4, 17 February 1976, Appendix 5, 15 March 1976).

2. THE TOOLS USED IN THIS INVESTIGATION

Much of the work done under this contract was numerical simulations on the University of Nevada timesharing system and on a Lockheed MAC-16 minicomputer (Appendix 6, 1 June 1976). The University system was used mainly to assemble the MAC-16 programs and to try out ideas before the MAC-16 system was developed. A large set of software for doing realtime simulations was written for the MAC-16. This included everything from floating point addition to a diskette based operating system for the MAC-16 fortran compiler. The MAC-16 has 8K of memory, multiplexer channels, incremental plotter, Tektronix 4Ø14-1 CRT and a dual diskette drive. The MAC-16 was to model the experiment in realtime. That is, the simulated droplets would move just as fast as real ones would. The available floating point software was far too slow to keep up with the necessary amount of computation. So a whole new package of addition, subtraction, sine, cosine, etc. was written which kept fewer bits of precision but was quite fast. These pieces were combined into a simulator which displays droplet dynamics on the CRT screen. The simulator was used to show how the various strategies of operation would actually work. As a next stage of software development it was planned to interface the simulator to fortran language operation. Thus far all the operating strategies have been tediously coded in machine language. The testing of new ideas often became buried under endless rounds of debugging. A diskette operating system for running the Lockheed editor, assembler, and fortran compiler has been developed. Though primitive by modern standards, it fits in the limited memory space of the MAC-16 (8 K words). The next stage in software development would be to convert the simulator into an alternate fortran runtime library. This would make the whole package natural and simple to use.

3. A CLOSER VIEW OF THE EXPERIMENT

When one first sits at the simulator console, the droplets seem stationary. The screen shows a closeup of the two droplets and two markers the operator must match with the "real" droplets. Their motion becomes obvious, however, as one attempts to follow them with the joystick. The speed builds slowly but surely as the droplets drift towards the edges of the screen. The errors build too. The first small error in a position measurement grows to glaring proportions. Then there is a hurry to fix it in the time left. The droplets must not drift too far from the center before the computer gets control from the operator. Time spent watching the slow acceleration of the drops should have been spent molding the motion of the markers to the motion of the real drops. Then the computer takes over accepting the indicated positions as accurate. A series of quick manipulations aligns the droplets, offset from the center of the chamber. Then there is a scale change as the screen now displays the whole chamber as seen from a distance. The chamber shifts along its length to bring the droplets to the desired distance from the center. In the process the droplets have drifted nearly back to the centerline of the chamber. The chamber stops and reverses its motion to counteract the now rapid fall of the droplets. One is nearly held fixed on the CRT screen and the other slowly passes by a few hundred microns from the first. More accurate information from the operator would have narrowed the distance to a near collision. But most of the error came from a simplified method of aligning the droplets.

Use of the simulator makes clear that although the motion of the droplets is much slower than on earth, they are still moving. The alignment of the droplets must be completed before they drift too far. Eventually they collide with the chamber walls. To use the squirrel cage, both drops must fit inside. If the drops are too far apart, they may move farther apart rather than collide. That is, if the differential in the centrifugal force is great enough between the two positions, the lighter drop may actually fall faster than the heavier. This gives a design consideration for the droplet injector. It should leave the drops as close to the center as possible.

One thing that has been ignored in the simulator so far is that the droplet injector will leave the droplets in a volume of space, not always in the same plane. Thus a method (e.g. a squirrel cage) will have to be provided to bring the droplets to one level. This would also call for a second set of optics at right angles to the first. Another possibility would be to use the limited depth of field of the optics to find the droplet's third coordinate. If digital imaging were used the computer could find the depth by seeking the level of maximum contrast. A digital system has other advantages also. It would remove the human element from determining position and droplet radius. The continuous stream of position information would locate the droplets much more accurately than the raster dimensions. The main disadvantage is the increased computation load on the computer which must sift through great volumes of data to keep track of the droplets.

The operation of this experiment requires that the position and size of each droplet be accurately known. The size can be determined from two time and position measurements since size is related to rate of fall. In practice the accuracy is limited by the resolution of the measuring device and the skill of the operator. To overcome this a least square fit from several measurements was tried. With an ideal operator this would have yielded accuracy of about 1/2% in the droplet radius after 3 or 4 position measurements. In practice random and systematic errors limited this to 2 or 3%. A second method that was tested shows the operator how close his last guess corresponded to reality. If the simulated position deviated from the real position, he could move the simulated drop to where it belonged. This would tell the computer how far the earlier radius estimate deviated from reality. When the estimated radius deviated considerably from the true one, this yielded results good to about 1%. One must look more carefully to notice small deviations, but this would come with more practice. The main disadvantage was that position estimates did not improve with the number of measurements. The least square fitting of the first method could be incorporated with this second method to give the advantages of both.

Once the size and positions of the droplets have been determined the droplets must be moved out some distance from the center. They must arrive here aligned so that one collides with the other. This requires considerable prearrangement to achieve. (This is called prealignment below.) The biggest effect is Coriolis force during the move. The droplets must start some distance from the midline of the chamber to end up on the midline after the move. The procedure to move the droplets from a position near the center to one offset to one side depends heavily on the positions and radii of the droplets. It was hoped to reduce this to a set of approximate formulas (Appendix 7, 1 July 1977, Appendix 8, 7 July, 1977). Using the University computer the prealignment procedure was determined for a range droplet sizes and positions. Then formulas were fit to these data. However, even formulas involving hundreds of terms proved inadequate. A workable solution is to use a simple formula to approximate the answer. Then simulate to see how close it is and use successive approximations to arrive at a solution. This means that the computer must be able to do 3 or 4 complete simulations in short enough time for the droplets not to get away from it (For example see Appendix 9, 15 March, 1978). The MAC-16 is not that fast so only the simple formula was ever implemented into the simulator.

4. RECOMMENDATIONS AND REQUIREMENTS

The experience gained so far indicates a number of requirements for the actual system to be used in earth orbit. The experiment could easily use one or more dedicated processors during operation. The control of stepping motors and internal environment must be precise and repeatable. This would be difficult with a computer that must take time out to handle "high priority" events. Since the computational load is not great here, this would be an ideal application for a microprocessor. The experiment requires a considerable amount of computation doing simulations. During a look-ahead simulation for the prealignment process, it would have to run about 50 times the realtime rate. This would require a floating point add time of less than 10 microseconds. Thus the experiment would need at least an upper grade minicomputer. The simulations could share a computer with other functions if the compute time was available during the short periods when it was most needed.

A great increase in computer load would also result if 1:1 scaling proves possible. This is rotating the chamber fast enough to generate 1 gravity fields and using smaller droplets. This has the advantage that earthside conditions obtain and no doubts can raise about the applicability of the results. However, the 10 micron droplets would move 3.3 times faster than the 33 micron radius droplets that are currently being modeled. This means that the computer simulations would have to run correspondingly faster in a computer of sufficient power. 1:1 scaling is probably only possible if the experiment could run without much operator input. This would be the case if digital imaging were used.

The optical system would need a clear flat field with low distortion. Some procedures call for combining the view of the droplets with a computer display. This would need to be done very accurately with provisions to prevent parallax errors, etc. A CRT display would make this easier. A step further would be a digital imaging system. This, of course, would add a continuous high computation load to the computer.

5. AREAS FOR FURTHER INVESTIGATION

The largest area that has not been touched is the design of hardware. Droplet generators need investigation. The number of experiments that can be run per hour depends on how often the generator can deliver droplets of the desired size range to the desired area. Stepping motor systems which move accurate distances at controlled rates are needed. Clear low distortion optical systems play an all important part to the operation of the whole experiment. A more immediate need is better joystick input for the simulator. The current one is very slow and clutters the display with extraneous lines.

Software development must keep space with that of hardware. For example, the procedure for prealignment of droplets depends on the exact manner that the stepping motors operate. It also varies when the experiment is rescaled to use droplets in a different size range. In fact, it would be desirable to make the final version adaptive. The program would use its experience with real droplets to improve its performance on further trials.

The investigations so far have brought out some of the ways in which the experiment could operate. However, the design is by no means fixed. New ideas still occur which could change the apparatus considerably.

6. SUMMARY

This project is still in the conceptual stage, but the simulator has given much information on the problems yet to be solved. At this point, basic strategies for operating the experiment have been mapped out. The problems remaining lie in the area of developing the hardware to do the tasks needed.

The simulation performed on this contract has been a fairly sophisticated numerical simulation of behavior of cloud droplets in an experiment suitable for an orbiting laboratory. The simulation will become a part of the real experiment when it is actually put into execution. A copy of the mini-computer (MAC 16) coding is attached. The basic feasibility of the computational approaches have been demonstrated, and numerical alternatives evaluated. Computational speeds have been addressed and are well within the state of the art.

APPENDIX 1

Cloud Droplet Coalescence Experiments in Orbit

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CLOUD DROPLET COALESCENCE EXPERIMENTS IN ORBIT

1. INTRODUCTION

Any attempt to justify a substantial effort to study the processes of nonfreezing rain formation is inadequate unless we recognize that cloud droplets are not raindrops and that condensation processes can never grow a drop large enough (say to one millimeter in diameter) to be a raindrop. The importance of the condensation process is that it forms the cloud in the first place and in so doing provides the supply of water needed for the ice forming process to proceed or for coalescence to occur and raindrop sizes to be produced.

The difference between the initial condensation process and the ice particle formation stage is in the number of particles which can act as nucleating agents. Even modest supersaturation in the normal atmosphere produce an abundance of particles able to act as nuclei and it never occurs that only one particular per liter activates. If the latter were to happen rain would be produced directly from clear air, and condensation rather than icing would be the principle aircraft hazard.

However, condensation nuclei are numerous and ice forming nuclei are rare, so clouds containing many small drops are formed which supercool readily as the cloud rises and cools below freezing. Then the few nuclei which activate to initiate ice particles, rapidly acquire all the water available by vapor transfer, giving large particles which precipitate as rain or snow. In this context it seems unlikely that a factor of, say 10 or more, in cloud droplet sizes or number concentration could have any effect on the ice based rainforming processes. If this were true then the study of the condensation process might be thought to be an academic exercise, unless it could be proven that most rain actually did form by coalescence. However, Hallet and Mossop (1974) have advanced an interesting hypothesis that ice crystal production occurs during the freezing of the largest cloud drops, thus intimately relating cloud drop sizes to all rainforming processes, and in particular to the initial phases of severe thunderstorms.

The physics of rain formation by the coalescence mechanism is quite different from that involved in the ice process. The drop sizes needed to allow numerous cloud droplet collisions is larger than condensation processes usually give with typical nuclei counts, because small drops do not touch but slide apart on collision. Hence a thorough understanding of the condensation process is a necessary step in understanding non freezing rain. This knowledge will be incomplete however, unless we know the next link in the chain of events leading to rain formation, the coalescence mechanics. The continued efforts to elucidate the details of the condensation process is partly justified because we believe coalescence studies have shown that only large drops (i.e. > 18 μm radius) can grow by collision. The verification of the theoretical estimates of the coalescence rates is thus equally important (as indeed is an adequate study of the modifications possible in the cloud spectrum by the turbulent mixing in of dry air, which now also appears to be important) to determining cloud droplet spectra.

2. SCIENTIFIC BACKGROUND

In the past 20 years the physical process which allows rain to form by the aggregation of cloud particles has been the subject of detailed modelling. The instability of a cloud composed of the many small water drops which form by the initial continuing process of condensation was recognized many years ago by Bergeron. He understood that the drops which cooled in a rising cloud of air did not freeze immediately on reaching the normal freezing temperature at 0 C. However, as an associated effect of this supercooling the vapor tends to transfer to any ice in the vicinity below this temperature. The difference in the vapor pressure between that over the water and the smaller pressure over ice at the same temperature, results in the very rapid growth of those first few ice crystals formed in the supercooled water cloud, using up the water lost from evaporating drops.

While this process had been generally accepted however, it was not long until (before 1950) aircraft observations convincingly demonstrated that rain often fell from clouds in which no ice could reasonably be thought to exist. These clouds were warmer than the freezing point of water in their coldest tops. The existence of this phenomenon necessitated an alternative explanation. Thus it was conceived that slight differences in cloud drop sizes would enable the bigger drops to catch up with any smaller slower drops beneath them and on contact join up to give a bigger drop which would repeat the process.

It was soon apparent that at cloud drop sizes the flow of the air around the drops did not result in one drop gliding up to another as though it was not there until it bumped into it. The movement of the air in the front of the larger drop pushes the lower drop out of the way and the result is that at small sizes drop interactions rarely result in collisions.

The transition between cloud droplet sizes where most intersecting paths of falling droplets result in collisions, and the alternate case where there are very few collisions, occurs with decreasing drop sizes just before sizes become as small as the drops in real clouds.

Observations of real clouds show however, that rain does fall from relatively thin clouds in relatively brief times of twenty minutes or so. Crude theory requires much larger times. The stochastic problem of the collision dynamics was formulated quantitatively by the author (Telford, 1955) when he included in the calculation, the low probability, but highly significant, faster than average growth by the few largest droplets. Even so these considerations do not give adequate growth rates even when using the present highly sophisticated theoretical values for the collision efficiencies.

Furthermore these theoretical values for the collection efficiency have never adequately checked in the drop size region of interest. The experiments are exceedingly difficult, using as they must nearly equal droplets of less than 40 μm diameter. Numerous peripheral measurements have been performed using bigger drops or drops in a continuous stream but these do not address the real problem. The experimental difficulty relates to handling the drops so they can be precisely positioned before being dropped into the fall trajectories which lead to the collision dynamics.

Another fundamental problem which could be resolved in a good experiment relates to the method whereby the initial microscopic bridge of water occurs between the two droplets at the initialization of coalescence. It is well known that electric fields make an enormous difference in the behavior of drops skating over a flat water surface. Any appreciable field results in the drops immediately coalescing with the surface. For unequally charged drops the interdrop field, of course, rises without limit as the drops approach to spaces below 1 μm. It is of both fundamental and practical importance to know whether drops will coalesce without the help of some electric field between them.

The stability of clouds and fogs may occasionally be a consequence of the total absence of electric effects to aid coalescence, or the presence of small, like, charges on the drops. It is also vital to check the theoretical calculations of the collision dynamics itself because of other approximations involved. Any appreciable deviation from the present theory could well have marked effects on the rate of growth of droplets in clouds and fogs by coalescence.

The author performed a large number of experiments in about 1955 to check effects of surface active agents on drops about 150 μm in diameter and found no effect on the coalescence or "bounce" rate between drops. Hence most "bounces" in fact probably do not involve surfaces separating from distances of less than 0.2 μm, say. Later experiments showed a large influence from horizontal electric fields at diameters of 20 μm.

More recently Neiburger, Lee, Lobl and Rodriguez (1974) have done a series of experiments at these small sizes from which they conclude that their smaller measured values of collection efficiences deviate from both theory and previous measurements, and that the logical deduction from this is that coalescence does not occur unless there are small residual charges on the drops.

Thus any accurate explanation of the rainmaking process will involve the building of a precise numerical model which depends almost entirely on knowledge of this coalescence process when freezing has not become active, and may be dependent on this information even where ice processes have become active at some later stage.

3. HISTORY OF COALESCENCE

The history of the coalescence problem began with Bowen's (1950) calculations on the growth of drops in warm clouds. Langmuir understood the collection efficiency problem, from his work on aircraft icing where a similar form of collection efficiency is important. He calculated the collection efficiency for a large collecting drop with potential fluid flow (infinite Reynold's number) and a small drop with viscous flow drag (zero Reynold's number, or Stokes' Law). He did the same calculation when the collecting drop was small and also had a zero Reynold's number for the flow around it. He then used an intuitive method to interpolate between the collection efficiencies calculated for an infinite Reynold's number collector and the collection efficiencies calculated for a zero Reynold's number flow at the collector. He thus derived a figure for the collection efficiency for the collector drop at the Reynold's number appropriate for its size. There was an obvious need to check this work experimentally and during experiments which this principal investigator undertook the wake collection effect was discovered at slightly larger than cloud drop sizes (Telford, Thorndike and Bowen, 1955; Telford and Thorndike, 1961). Then Hocking (1959) produced this solution for both drops having small enough Reynold's numbers so that his series solution converged. He assumed the equations were sufficiently linear (i.e. zero Reynold's number) so that the actual flow patterns around the drops could be formed by addition of a solution for motion along the line of centers and a separate solution for motion perpendicular to the line of centers.

This resolution is only strictly valid for a zero Reynold's number (viscous or Stokesian flow) as only in this case is the drag force exactly proportional to velocity, so allowing the superposition of solutions. Zero Reynold's number however precludes the wake collection effect observed at larger sizes. But only for zero Reynold's number will the vector force due to two separate calculations of the forces, using the specified resolved velocity which is the vector combination of the two components of the velocity. Thus, Hocking's numbers for the collection efficiencies failed to consider the approximations in this force resolution approach.

Analogy approaches were tried. Sartor (1954) produced an erroneous analog in which he did not try to make the densities of the drops and their medium take on the correct ratio, and thus the approach was not exact. The density ratio for oil drops in water in no way approaches the 800:1 ratio of densities met in clouds of water drops in air. Attempts were made to solve this problem by "simulating" high densities (i.e. 800 gm cm^{-3}) using metal balls in oil with large masses rigidly attached (Telford and Cottis, 1964).

To reiterate, vital interest in the collection efficiency arises because the Reynold's numbers of the droplets in clouds is too large to be considered zero, but far too small to allow potential flow solutions to be useful, thus posing an extremely difficult theoretical problem. Clouds are however observed to rain in conditions where coalescence proceses appear to be the only possible mechanism.

Hocking's collection efficiencies predicted no drops would coalesce unless their radii exceeded 18 μm. This process demands an improbably large size for drops to occur in clouds by condensation growth, in the conditions usually occurring.

Sartor, apparently realizing the difficulties of analog simulation and experimental measurement with cloud sized drops (for previous experimental work in this area see Telford and Thorndike, 1961; Woods and Mason, 1965; Picknett, 1960; and Woods, Drake and Goldsmith, 1972) encouraged Bill Davis to rework the problem theoretically (Davis and Sartor, 1967). The experimental work at UCLA with Neiberger and Pruppacher was based on confirming the theory by experiments with heavy metal balls in viscous fluids (density ratios of less than 20:1). More extensive theoretical work was undertaken by Hocking and Jonas (1970) who took account of the force couples on the drops at close approach and also used the improved approximation to the theory given earlier by Davis and others. They also point out that collision is impossible if Stokesian (viscous) flow is preserved at close approach. Davis (1972) treated the problem of the final thin film of air between the drops.

All these treatments assume zero Reynold's number (Stokesian or purely viscous flow) in separating the flow field solutions. The wake effect observed experimentally, and for which there is some evidence at Reynold's numbers approaching the values found in cloud droplets, is a direct manifestation of non-Stokesian flow. Thus the zero Reynold's number on which the theory is based remains in need of verification.

Bartlett (1970) used the Hocking and Jonas' (1970) calculation to look at the evolution of a possible cloud drop spectrum. He examined the modification of the cloud drop spectrum and shows the spectrum of large cloud drops sometimes observed in clouds could not be obtained this way. However, he equated the changing whole cloud drop spectrum with rain formation, which is not satisfactory. As Telford (1955) showed, the growth of raindrops may be quite separate from any large modification of the droplet spectrum at cloud drop sizes. The majority of cloud drops have their sizes determined by coalescence, condensation and mixing, in their passage up through the cloud. Rain is formed by about one in 10^5 of these drops growing faster than the others by virtue of experiencing collisions very early in the cloud process, and using this advantage to grow to raindrop sizes while the other cloud drops are still only a few tens of microns in size.

Thus Bartlett's conclusion that clouds formed of large drops will not evolve to the super large drop spectrums sometimes reported, by coalescence alone, is not the central issue. Incidentally, a large number of large cloud drop spectra sampled with oil coated slides simply demonstrate that coalescence of the captured cloud drop occurs on the collecting slide. The real issue is whether coalescence processes allow the very few droplets needed to produce rain to start growth soon enough after condensation begins, to give them the time advantage needed to form rain before the cloud evaporates.

In fact the lifetime of clouds, if the microphysics were different, would become larger and larger until rain formed frequently enough to stop the average moisture in the atmosphere from increasing any further. Thus, the problem is one of determining an explanation of why coalescence processes in warm latitudes over the sea operate as quickly as they are observed to do. Thus the interest in coalescence processes is in relatively rare events that occur much earlier in time than the time when the average collision will occur. The theoretical work is very valuable but we should beware of accepting the view that such calculations have settled the problem, without experentl checks.

The urge to get on with it often produces the attitude that the best to date must be good enough, unless there is a simple path to an easy improvement. Berry's recent work integrating the stochastic equations is questionable for this reason. He does not appear to have treated the problem of how the first bigger cloud drops form (say those greater than 15 μm radius) but has treated the calculation of how the raindrop spectrum evolves after this has happened and in non turbulent clouds. This problem is compounded by the fact that there is no well founded logical basis for integrating growth in a smooth updraft when we know what we do now know about the large turbulence in clouds.

Thus, there is presently a tendency to say that the interesting part of the coalescence problem remaining to be solved is what happens when the drops are very close. We suggest here that the important thing is to develop any sort of experiment that works with water drops in air at sizes close to real cloud droplets sizes. Experiments in liquids (i.e. water drops in oil) are always suspect because of double layer phenomena which produces surface repulsive layers which do not occur in air.

Once a reliable experimental technique is available, experiments can be performed using surface active agents in the water or other liquids besides water. Previous experiments in about 1955 by the author with larger drops (150 microns) indicate that surface active agents, e.g., hexadecyl-tri-methyl ammonium bromide, produce very little effect on water drop collisions in air although for bubbles and liquid drops in water the effects are large.

4. DROP DISTORTION

It is sometimes suggested that using larger water drops under lower gravity will not model the surface tension forces and thus give uncorrectable errors. Let us now look at the suggestion that the distortion of the drops during collision may play a role in the dynamics. This should be checked by using drops with a higher or lower surface tension in the experiment but let us reason as follows.

In a sphere in an acceleration field we have a pressure gradient within the drop. Thus, the curvature at the top and bottom of the drop will differs slightly.

If the surface tension is T then in a non-accelerated drop of radius r the pressure is,

$$P = \frac{2T}{r} .$$

This applies also to any spherical cap of radius r.

The pressure gradient in the drop is, where a is the acceleration and ρ the density,

$$\frac{dp}{dz} = \rho a.$$

At the top and bottom of the drop there is very little tangential airflow so the internal pressure will rarely determine the surface curvature (we ignore internal circulation although this should model correctly in the case of the experiment which we hope will be an outcome of this work).

The average pressure in the drop will be

$$P = \frac{2T}{r} .$$

The pressure deficit at its top will be,

$$\Delta P = - r\rho a .$$

Thus

$$P_{Top} = P + \Delta P = \frac{2T}{r} - r\rho a = \frac{2T}{r_{Top}}$$

$$\frac{r_{Top}}{r} = \frac{2T}{2T - r^2 \rho a}$$

$$= \frac{1}{1-r^2\rho a/2T}$$

$$T = 76 \text{ dynes/cm}$$

$$r = 50\text{x}10^{-4}\text{cm}$$

$$= \frac{25\text{x}10^{-6}a}{150} = 1.7\text{x}10^{-7}a$$

For a 1% effect on the drop curvature,

$$a = \frac{0.01}{1.7\text{x}10^{-7}}$$

$$= \frac{10^5}{1.7} \simeq 6\text{x}10^4 \text{cm sec}^{-2} .$$

Thus the distortion of such a drop under its own weight is quite negligible.

To es 5ate the acceleration during a drop collision assume the drop moves aside by one drop radius in the time the drop takes to move forward one diameter.

The terminal velocity in the experiment is 0.18 cm sec^{-1} and hence we might assume a relative velocity of 0.1x0.18. Thus,

$$a = \frac{r}{[2r/(0.1\text{x}0.18)]^2}$$

$$= \frac{1}{12345r}$$

$$= 0.024 \text{ cm sec}^{-2}$$

$$= \frac{g}{40,000}$$

Thus the acceleration of the drops in the experiment is about 10^6 times too small to produce perceptable drop distortion.

As a check on the surface tension formula consider the average radius of a drop which is big enough to give the curvature of the top surface as half the average curvature in a 1 g field (i.e. under its own weight).

$$\frac{r^2 \rho a}{2T} = 1/2$$

$$r^2 = \frac{T}{\rho a} = \frac{76}{1x10^3}$$

r = 0.28 cm which agrees with the observation that 3 mm radius water drops show marked flattening.

The real answer to the question of the non-perfect analog of the cloud drop collisions is of course that we can readily use the apparatus to simulate 1 g or so we have every non-dimensional number exactly correct. The essence of the experiment is that zero-g conditions allow opportunity to arrange the positions of the drops precisely before they start falling. Thus we should have no fundamental problem in extending the experiments down to 20 μm radius droplets in a 1 g field. It should be pointed out at this stage that the plane of the collision can be arranged so that the acceleration of the drops is not in the direction of the Coriolis forces and hence such effects should be secondary. With the ability to study the larger cloud drop sizes at correct and constant Reynold's number but varying other parameters of analog simulation away from their exact values, the experiment should shed light on their importance.

This experiment is one which cannot be performed in the earth bound laboratory because of the enormous difficulty of controlling the position of the two drops before the collision process starts. Flinging the drops into position from a vibrating hollow needle in a stream of one drop after another creates flow forces on the drops which tend to align the drops before the drops have decelerated to the velocities comparable to the initial conditions of approach experienced in clouds, and this unrealistic beginning to the collision trajectories can have a profound effect on the measurement (Telford, 1966). In the zero-g experiment the process can be started from rest with precise positioning.

The experiment is important because the theoretical description of the process involves assumptions the evaluation of which are a matter of faith. The understanding of the phenomenon is important because even if the formation of warm rain cannot be explained in this way as a coalescence phenomenon we are left with a problem which, when solved, could have far reaching effects on all rainforming theories and techniques of weather modification. If rain can be explained as the result of coalescence we need to know how, so as to evaluate its influence in all rainforming processes. Freezing rainforming processes cannot act in clouds wholly above zero in temperature. Coalescence processes will always be in action unless the collection efficiencies are truly zero.

The proposed experiment offers a tool in which other efforts on coalescence, dust in the air, electric fields, sudden acceleration of the air during, close approach to simulate turbulence, etc. can be evaluated once the technique is established.

5. THE EXPERIMENTAL APPROACH

The possibility of an experiment under very low gravity allows a new freedom in planning experimental measurements of the efficiencies of collection between cloud drops. To correctly simulate the dynamics of droplet collision it is necessary to maintain the Reynold's Number of the flow correct at each geometrically similar point while the colliding drops approach each other. To do this it is not sufficient to arrange the sizes of the drops and the viscosity of the fluid so the Reynold's Numbers are correct when the drops are well separated. In addition, it is necessary to have the density of the drops relative to the surrounding fluid the same as for water relative to air, about 1000:1. Only then will the Reynold's Numbers of the drops remain correct as the drops accelerate when the trajectories curve on close approach.

The desirability of modeling the drop collision phenomenon comes about because of the difficulties in working with water drops some 10 μm or so in diameter. Two fundamental problems arise. The first is the virtual impossibility of positioning two drops one above the other and a hundred diameters apart vertically in such a way that the horizontal separation of the projected paths is known, and secondly, the smallest air currently seriously disturbs the paths of the drops falling at a few centimeters per second. Choosing pairs of drops in a projected stream of droplets from a vibrating needle is useless since the collision dynamics are well advanced, in an entirely different dynamical regime, before the drops slow down in the observational field. On the other hand, random collisions between well isolated drops are too rare for profitable observation and a dense cloud of drops introduces its own circulation problems.

The virtue of modeling experiments performed under conditions of zero gravity is that the drops can be arranged manually before release. This paper describes a method of use in a zero g laboratory to take advantage of this condition with water drops falling in air.

6. BACKGROUND TO COLLISIONS UNDER LOW GRAVITY

The opportunity to virtually turn off gravity at the center of mass of the capsule allows an adequate setting up procedure since the drops remain almost unmoving. The turning on of linear gravitational acceleration at 1 g would be difficult in a capsule because of the large velocities involved. However, it turns out that small controlled circular accelerations bring major advantages to the experiment in the form of allowing larger drops and slower speeds to retain dynamic similarity. The flow appears to be exactly analogous but for this to be true the ratio of the drop density to that of the surrounding fluid must be the same as for water drops in air, and hence the experiments require a liquid moving in a gas. Water in air is the obvious choice because it is harmless and will stimulate actual coalescence much better, the different drop surface curvature being the only essential change.

For lower gravity the formulae for the terminal velocities of drops are as follows:

Stokes Law gives,

$$F = 6\pi\eta r v = 4\pi(\rho-\rho')r^3 g/3$$

$$v = 2(\rho-\rho')gr /9$$

$$R_e = 4(\rho-\rho')gr^3/9\nu^2\rho'$$

where

$\nu = \eta/\rho'$ = kinematic viscosity of air

η = dynamic viscosity of air

ρ = density of water

ρ' = density of air

r = drop radius

g = acceleration due to gravity

R_e = Reynold's number

Thus, in simulation with reduced g, using the subscript e to refer to normal conditions on Earth,

$$\frac{R_e}{R_{e_e}} = \frac{gr^3}{g_e r^3{}_e}$$

Hence, if we plan to set up an experiment at zero g in a small package and then accelerate at $10^{-3}g$ we can simulate by using 200 μm drops the collisions of two nearly equal drops in the atmosphere, of diameters 20 μm (we need to simulate diameters from 20 μm to 40 μm).

The terminal velocity of the 200 μm drops at $10^{-3}g_e$ will be (for $R_e = R_{e_e}$),

$$v_e gr / g_e r_e = v_e r_e / r = 1.2/10 = 0.12 \text{ cm sec}^{-1} .$$

Hence the simulated drop moves through its surrounding air a distance of about 6 radii each second. If we plan on a 1% difference in the terminal velocity of two drops set up for collision at a distance of 30 diameters apart they will need a time of,

$$t = 60x100r/v = 6000\ r_e/v_e\ (g_e/g)^{2/3} = 5(g_e/g)^{2/3} ,$$

so that about $10^{-3}g_e$ the experimental drops will take about 8 minutes to collide. If this occurs in a linearly accelerating chamber accelerating at g, the chamber will move

$$L = 1/2gt^2 \zeta\ 12g_e(g_e/g)^{1/3}$$

or a distance of 1200 meters or more.

This approach would thus require acceleration of the spacecraft. Sustained acceleration is obtainable from the gravity gradient across the spacecraft. However, this is of the order of $10^{-6}g_{e}/m$. This low number suggests an even more desirable experiment where the drops used are 2000 μm or 2 mm in diameter and the experiment runs for a time of 1000 minutes or 16 hours. This would, however, involve servo control of the spacecraft to keep the experimental chamber in free fall within an experimental volume where the only force on the experimental container is a controlled force generating the $10^{-6}g_e$ acceleration. Since the 2 mm drops need to move 6000 x 2 mm within their immediate airspace the chamber would also need to be this long and adjusted so the gravitational gradient along it was either negligible or used so the drops always experienced the correct acceleration.

Considerations of trade-offs along this line of thought depend on engineering data unavailable to the author, in particular, the spectral density of the g noise, which has only been mentioned as of the order of $10^{-4}g_e$. However, this approach seems impractical at present and an alternative approach is recommended, which is much less demanding and should give the desired results.

Thus, the practical approach to using a very low acceleration (e.g. $10^{-4}g_e$) is to set up the drops in their initial condition and then apply an acceleration by swinging the chamber in a circle.

When the drops have a diameter of 200 μm a fall dtance of 6000 diameters is 120 cm and hence the fall space in the chamber would have to be about this length. To achieve an acceleration of $10^{-3}g_e$ or 1 cm sec^{-2} the circular path and velocity are given by

$$1 = r\Omega^2$$

If r = 30 0, Ω = 0.18 radians sec^{-1} or a full circle is T = 35 seconds.

Thus a free space allowing a circular swing of about 2-1/2 m diameter is needed for this experiment.

Since such a size may be unwieldly it is suggested that the optimum result will come from choosing the instrument to fit inside a 60 cm diameter space. Thus, the maximum length of fall is about 20 cm with the drops moving on a 10 cm radius circular path. Thus, the drop diameters should be 20/6000 = 33 μm in diameter.

This size drop calls for an acceleration of $g_e/4.49 = 218\ cm/sec^2$.

If the radius arm is 10 cm = $(218/10)^{1/2}$ = 4.67 radians/sec.

T = 1.35 seconds per revolution.

The time needed for the drops to fall is t = 14 seconds.

Thus, while the drops are smaller than desired the experimenBkks practical to perform under low gravity conditions. At D-2

Thus, for a 10 cm radial distance of the rotating chamber

= 1.6 radians/sec

T = 3.9 sec

The time for the drop falling is

= 44 seconds

This final configuration looks the best particularly if a total diameter greater than 60 cm is feasible.

7. THE EXPERIMENTAL METHOD

Thus, the experiment would be planned to visually adjust the position of two drops using small air jets, acoustic manipulators or the centrifugal acceleration gradient, while on the axis of rotation of a transparent square tube rotating around a line perpendicular to the tube through one end. In this essentially non-accelerated region the task of adjusting position can be done at leisure and may well take 10 to 15 minutes to set up a required drop collision. This overcomes the problem met in terrestrial experiments associated with the impossibility of positioning the participating drops as needed.

Acceleration is then applied to the drops by moving the transparent square tube along its axis away from the axis of rotation until the drops themselves are 10 cm from the axis of rotation. Here the acceleration is 26 cm. $sec.^{-1}$ and this is maintained by moving the transparent tube back along its axis so the drops are always 10 cm from the axis of rotation.

Since we are considering 67 μm diameter drops 30 diameters apart this is a separation of 2 mm in 10 cm and the centrifugal acceleration difference is 2% which is negligible. Similarly the gas will have virtually no motion induced by these accelerations. g_e gives at 1000 mb pressure a pressure gradient of 0.12 mb m^{-1}. The effects in this experiment on gas compression are thus very much less than 1 in 10^4 and so are negligible. Gas temperature and moisture differences should be evened out by stirring between each experimental run.

The drop motion can be photographed with two perpendicular views superimposed in color on the film.

It is essential for the success of this experiment to provide the operator with a good viewing and manipulation facility since the essential capability this experiment offers is the ability to initialize the drop motion precisely as needed without throwing a stream of drops into place along a track, or picking pairs at random or using some other expedient which has so seriously hampered terrestrial approaches to this measurement problem.

The figures show the experimental device and how the drops can be viewed while in the rotating experimental space. The optical device (or some other visual display device) would keep the drops central in the field as they were moved radially outwards and removed the rotation from the image. They would be adjusted to their initial positions by acoustic or other mothods when in the zero gravitational field on the axis of rotation of the apparatus. Then the tube would be moved radially on outwards until the drops were rotating on a 10 cm radius circle and experiencing the "gravity force" from this centrifugal acceleration. Their position would be maintained at this radius, as they fall, by moving the enclosing tube radially.

The dynamics involved in moving the drops out from the center could be calculated accurately since Stokes' law applies when they are well separated at this stage of their fall. A digital simulator could be put together fairly readily for allowing practice of the setting up procedure.

8. INVESTIGATIVE APPROACH

This project has been concerned with examining the details of initializing the droplet collision processes. This has been more than half accomplished to date and involves producing the mathematical routines and programming them to run on both a CDC 6400 computer for checking out convergence problems in the integration, etc., and in real time on a minicomputer owned by the laboratory, to displaying the drop behavior on a display screen. The purpose of this work was two-fold, to show by simulation that the experiment was practical to control by a human operatond to provide a simulator for planning the actual experimental details. We have produced a substantial number of mathematical routines able to simulate the drop behavior when falling in the rotating chamber but well separated so drop interaction is negligable. The only practical way to perform the experiment is to mathematically predict the positions to which the drops must be moved before they start to fall together. As they move out from the rotation axis in the rotating tube their paths are quite complex, far too complex for an operator to guess at where they should start. Hence in initializing the position of the drops their positions will need to be accurately recorded in the computer as the payload specialist continually keeps the drops located by adjusting separate crosshairs for each drop in the viewing device.

Most of the positioning can be accomplished by rotating the chamber in a controlled manner as the computer routines predict drop collisions, or miss distances. In this way the drops can be initialized in positions which, for simple geometric collisions, would range from a near miss from one side to a near miss from the other side. The proportion of actual coalescences to coalescences expected on simple geometric considerations, then leads to collection efficiency values (the linear collision and coalescence cross-section needs to be squared to give the usual formulations for collection efficiency which is based on area).

More laboratory work will need to be done with actual drops before a final design of the experimental procedure can be specified. We need to know how well we can manipulate two closely spaced drops in zero-g, with some of the current drop manipulation procedures now being developed by various interested experimenters. The availability of precise pinpoint control, for example by laser beam, could modify the experiment.

However, experimenters have been generating small drops for fifteen or twenty years now and it is more a matter of selecting a technique and refining it to the stage where it will operate reliably, rather than developing a new approach. Thus, generating a stream of droplets from a vibrating hypodermic needle is an acceptable technique if it can be made to operate reliably with the skills we can expect from a payload specialist. Depositing two nearly equal droplets very close together in the chamber is exactly what we need here since the centrifugal force will slowly separate them, and after having come to rest any deleterious wake effects biasing the experiment after leaving the needle will no longer apply. Hence it is probably a practical technique to charge all but selected droplets by a photo-electric synchronized charging plate near the needle and to thus extract all unwanted droplets from the stream. Thus, pressing a button could be arranged to give one drop.

After the drops are located the computer could then indicate if they are suitably positioned to give a later position for collision, and if not then call for another one to be supplied, relying on the inherent random scatter from the needle generator to provide the variety of positions required.

Our numerical experiments have been based on rotating the air around the two drops by means of a circle of thin wires parallel to the axis of rotation. Such a structure can be built so that these "squirrel cages" can enter the air from positions flush with the tube walls and turn sufficiently to rotate the angle between the drops relative to the rotating tube. If done slowly there will be negligible turbulence created. Possibly a complete cylinder of very thin metal may prove satisfactory. The numerical simulation shows such a procedure should be satisfactory if we can inject the drops closely enough in the first instance, and measure their positions accurately enough.

The initial simulation was achieved with the operator shifting the cross hairs from one drop to the other, alternately, as the simulated drops drift on the screen in the way they would drift in the rotating tube. (See figures in the appendix for the apparatus).

This procedure indicates that all is well in anticipating a practical experiment. However, this is not an adequate way to assess the degree of skill needed to do the experiment in real time.

The simulation has been improved in terms of human interaction to make it more satisfactory. We have added to the display two small crosses showing where the drops being matched to the simulated drops by the monitor program appear in space so the operator can concentrate on improving the match where most needed, rather than trying to give exact information when a lot of approximate positions would be of much more use, and vice versa. The software routines in the monitor program solve a number of complicated fitting and dynamical problems in real time in order to achieve these results. This software is needed to run the zero-g experiment when the time comes. At some final stage, the drop simulator must be replaced by the real apparatus with the real drops in it.

The program at present simulates all the forces on the droplets when the drops are well separated and no interaction is occuring. Thus by following the actual drop motion (simulated by the computer at this stage) with crosshairs, under operator control, the monitor program estimates drop sizes. The program can thus control the rotation of the tube and "squirrel" cages to position the drops in such a way that a collision will occur later on down the tube, when the two drops have fallen after one another far enough for the dynamical interaction to be fully developed.

Further implementation of the experiment would include building and testing the computer controlled interfaces needed to control the mechanical operation of the experimental apparatus (see drawings for preliminary concept of apparatus). This includes computer interfaces and stepping motor drives for each necessary response to the monitor program.

In zero-g the observation of whether or not the drops coalesce, as a function of computed geometric position, gives the collection efficiencies we need. The computer simulation we are reporting here as the initial study will of course give only the geometrical, non-dynamical, interaction. However the whole system can be tested in this way up to this last stage, and operators trained, experimental accuracies refined, and the many minor problems cleared up before the final instrument is built.

The present software will provide the real time mechanical control to control the rotation rates, position the tube relative to the center of rotation, rotate the air around the drops, all according to mathematical simulations. Hence the drop motion should be strictly reproducible, and so the needed information can be obtained by recording the range of initial conditions which give a hit. Accurate tracking of the drop trajectories as they approach each other after the initial placement is, alone, sufficient to give the collection efficiencies.

9. SUMMARY

This report describes scientific studies undertaken to fill the gap left by the zero-g condensation experiments in order to give the latter work practical value in weather modification directed goals. If the condensation processes give cloud drops which are never going to coalesce then we are not studying the mechanisms truly responsible for rain formation. Thus we need to know precisely how much coalescence can get started at sizes before condensation growth becomes too slow to be important. It is presently doubtful that the condensation processes give rise to drop sizes for which the more rapid fall of the largest drops gives collisions and accretion by coalescence until rain results.

It is believed that the flow fields of the air around the tiny cloud drops prevent most collisions from achieving contact. However, the extensive theoretical work done on this subject needs to be checked by direct experiments with water drops.

The earth based laboratory experiments are almost impossible to perform without prohibitive restrictions. This study shows how conditions of zero-g can be used to overcome these problems and allow a well regulated and precise experimental situation.

There is a need to continue the preparatory work needed to specify the required apparatus, test its performance, make the measurements and analyze and supply the results.

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APPENDIX 2

Modeling of Cloud Drop Collisions with Low Gravity

MODELING OF CLOUD DROP COLLISIONS WITH LOW GRAVITY

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1. INTRODUCTION

The possibility of experiment under very low gravity allows a new freedom in planning experimental measurement of the efficiencies of collection between cloud drops. To correctly simulate the dynamics of droplet collision it is necessary to maintain the Reynold's Number of the flow correct at each geometrically similar point while the colliding drops approach each other. To do this it is not sufficient to arrange the sizes of the drops and the viscosity of the fluid so the Reynold's Numbers are correct when the drops are well separated. In addition it is necessary to have the density of the drops relative to the surrounding fluid the same as for water relative to air, about 1000:1. Only then will the Reynold's Numbers of the drops remain correct as the drops accelerate when the trajectories curve on close approach.

The desirability of modeling the drop collision phenomenon comes about because of the difficulties in working with water drops some 10 μm or so in diameter. Two fundamental problems arise. The first is the virtual impossibility of positioning two drops one above the other and a hundred diameters apart vertically in such a way that the horizontal separation of their projected paths is known, and secondly, the smallest air current seriously disturbs the paths of the drops falling at a few centimeters per second. Choosing pairs of drops in a projected stream of droplets from a vibrating needle is useless since the collision dynamics are well advanced, in an entirely different dynamical regime, before the drops slow down in the observational field. On the other hand random collisions between well isolated drops are too rare for profitable observation and a dense cloud of drops introduces its own circulation problems.

The virtue of modeling experiments is that the drops can be arranged manually before release. This paper describes a method for use in a zero g laboratory to achieve this same purpose with water drops falling in air.

2. BACKGROUND TO COLLISIONS AT LOW GRAVITY

The opportunity to virtually turn off gravity at the center of mass of the capsule allows an adequate setting up procedure. The turning on of linear gravitational acceleration at 1 g would be difficult in a capsule because of the large velocities involved. However it turns out that small controlled accelerations bring major advantages to the experiment in the form of allowing larger drops and slower speeds to retain dynamic similarity. The flow appears to be exactly analogous but for this to be true the ratio of the drop density to that of the surrounding fluid must be the same as for water drops in air and hence the experiments require a liquid moving in a gas. Water in air is the obvious choice because it is harmless and will simulate actual coalescence much better, the different drop surface curvature being the only essential change.

For lower gravity the formulae for the terminal velocities of drops are as follows:

Stokes Law gives,

$$F = 6\pi\eta rv = 4\pi(\rho-\rho')r^3g/3$$

$$v = 2(\rho-\rho')gr^2/9\eta$$

$$R_e = 4(\rho-\rho')gr^3/9\nu^2\rho'$$

where

$\nu = \eta/\rho'$ = kinematic viscosity of air

η = dynamic viscosity of air

ρ = density of water

ρ' = density of air

r = drop radius

g = acceleration due to gravity

R_e = Reynold's number

Thus, in simulation with reduced g, using the subscript e to refer to normal conditions on Earth,

$$\frac{R_e}{R_{e_e}} = \frac{gr^3}{g_e r_e^3}$$

Hence, if we plan to set up an experiment at zero g in a small package and then accelerate the package at $10^{-3}g_e$ we can simulate using 200μm drops the collision of two nearly equal drops in the atmosphere, of diameters 20μm (we need to simulate diameters from 20μm to 40μm).

The terminal velocity of the 200μm drops at $10^{-3}g_e$ will be (for $R_e = R_{e_e}$)

$$v = v_e gr^2/g_e r_e^2 = v_e r_e/r = 1.2/10 = 0.12 \text{ cm.sec.}^{-1}.$$

Hence the simulated drop moves through its surrounding air a distance of about 6 radii each second. If we plan on a 1% difference in the terminal velocity of two drops set up for collision at a distance of 30 diameters apart they will need a time of

$$t = 60 \times 100r/v = 6000\ r_e/v_e\ (g_e/g)^{2/3} = 5(g_e/g)^{2/3},$$

so that at $10^{-3}g_e$ the experimental drops will take about 8 minutes to collide. If this occurs in a linearly accelerating chamber accelerating at g, the chamber will move

$$L = 1/2gt^2 = 12g_e(g_e/g)^{1/3}$$

or a distance of 1200 meters or more.

This approach would thus require acceleration of the spacecraft. Sustained acceleration is obtainable from the gravity gradient across the spacecraft. However this is of the order of $10^{-6}g_e/m$. This low number suggests an even more desirable experiment where the drops used are 2000µm or 2 mm. in diameter and the experiment runs for a time of 1000 minutes or 16 hours. This would however involve servo control of the spacecraft to keep the experimental chamber in free fall within an experimental volume where the only force on the experimental container is a controlled force generating the $10^{-6}g_e$ acceleration. Since the 2 mm. drops need to move 6000 x 2 mm. = 12 m. within their immediate airspace the chamber would also need to be this long and adjusted so the gravitational gradient along it was either negligible or used so the drops always experienced the correct acceleration.

Considerations of trade-offs along this line of thought depend on engineering data unavailable to the author, in particular, the spectral density of the g noise, which has only been mentioned as of the order of $10^{-4}g_e$. Without knowing the excursions in position of the craft around the true central point nothing further can be done in this way and so an alternative approach is recommended which is much less demanding and should give the desired results.

Thus the practical approach to using a very low acceleration (e.g. $10^{-4}g_e$) is to set up the drops in their initial condition and then apply an acceleration by swinging the chamber in a circle.

When the drops have a diameter of 200µm a fall distance of 6000 diameters is 120 cms. and hence the fall space in the chamber would have to be about this length. To achieve an acceleration of $10^{-3}g_e$ or 1 cm.sec.$^{-2}$ the circular path and velocity are given by

$$1 = r\Omega^2$$

If r = 30 cm., Ω = 0.18 radians sec.$^{-1}$ or a full circle is T = 35 seconds.

Thus a free space allowing a circular swing of about 2-1/2 m. diameter is needed for this experiment.

Since such a size may be unwieldly it is suggested that the optimum result will come from choosing the instrument to fit inside a 60 cm. diameter space. Thus the maximum length of fall is about 20 cms. with the drops moving on a 10 cm. radius circular path. Thus the drop diameters should be 20/6000 = 33µm in diameter.

This size drop calls for an acceleration of $g_e/4.49$ = 218 cms./sec.^{2}.

If the radius arm is 10 cms.

$$= (218/10)^{1/2} = 4.67 \text{ radians/sec.}$$

$$T = 1.35 \text{ seconds per revolution.}$$

The time needed for the drops to fall is t = 14 seconds.

Thus while the drops are smaller than could be desired the experiment looks practical to perform under low gravity conditions. At these substantial accelerations the movement of the spacecraft would be negligible.

Let us repeat the exercise with half the initial separation of the drops which may be sufficient in most cases. If 20 cm. is 3000 drop diameters the drop will be 67µm. Thus we need an acceleration $g_e/38$ = 26 cm.sec.$^{-2}$.

Thus for a 10 cm. radial distance of the rotating chamber

$$= 1.6 \text{ radians/sec.}$$

$$T = 3.9 \text{ secs.}$$

The time for the drop falling is

$$t = 44 \text{ seconds}$$

This final configuration looks the best particularly if a total diameter greater than 60 cms. is feasible.

3. THE EXPERIMENTAL METHOD

Thus the proposed experiment is to adjust the position of two drops with optical observation using small air jets, acoustic manipulators or the centrifugal acceleration gradient, while on the axis of rotation of a transparent square tube rotating around a line perpendicular to the tube through one end. In this essentially non-accelerated region the task of adjusting position can be done at leisure and may well take 10 to 15 minutes to set up a required drop collision. This overcomes the problem met in terrestrial experiments associated with the impossibility of positioning the participating drops as needed.

Acceleration is then applied to the drops by moving the transparent square tube along its axis away from the axis of rotation until the drops themselves are 10 cms. from the axis of rotation. Here the acceleration is 26 cm./sec.$^{-1}$ and this is maintained by moving the transparent tube back along its axis so the drops are always 10 cm. from the axis of rotation.

Since we are considering 67µm diameter drops 30 diameters apart this is a separation of 2 mm. in 10 cms. and the centrifugal acceleration difference is 2% which is neglible. Similarly the gas will have virtually no motion induced by these accelerations. g_e gives at 1000 mb pressure a pressure gradient of 0.12 mb. $m.^{-1}$. The effects in this experiment on gas compression are thus very much less than 1 in 10^4 and so are negligible. Gas temperature and moisture differences should be evened out by stirring between each experimental run.

The drop motion can be photographed with two perpendicular views superimposed in color on the film.

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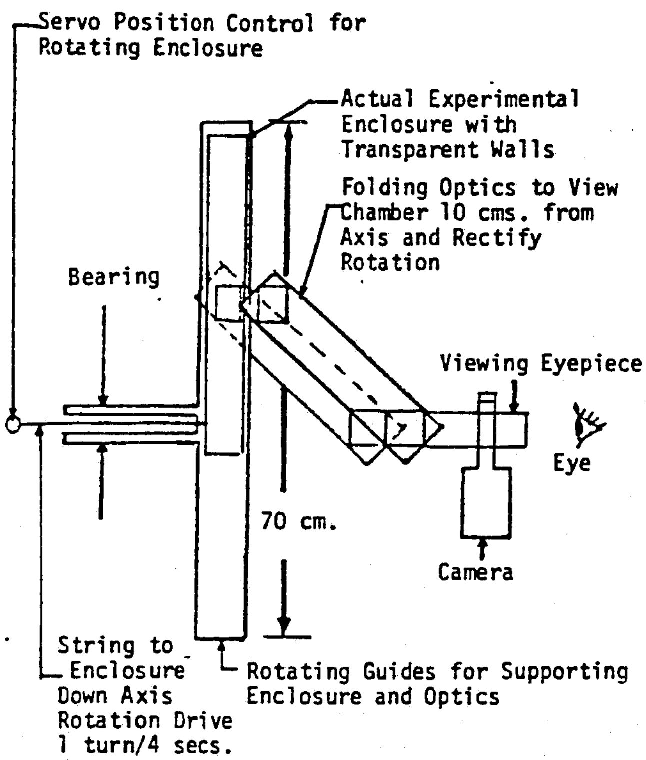

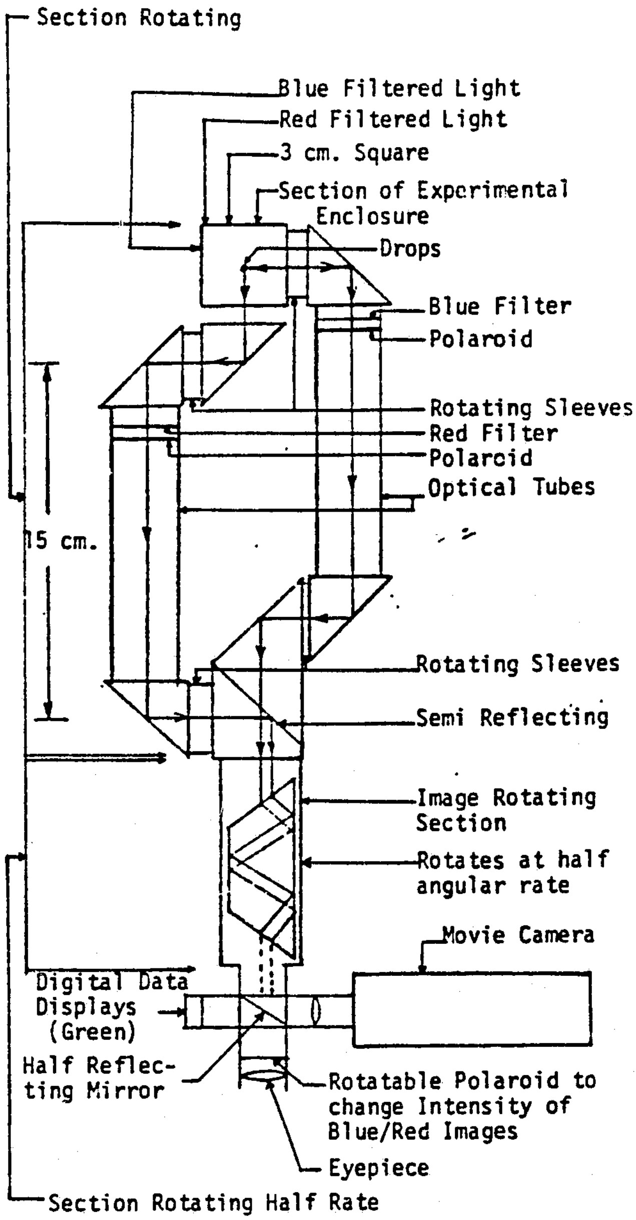

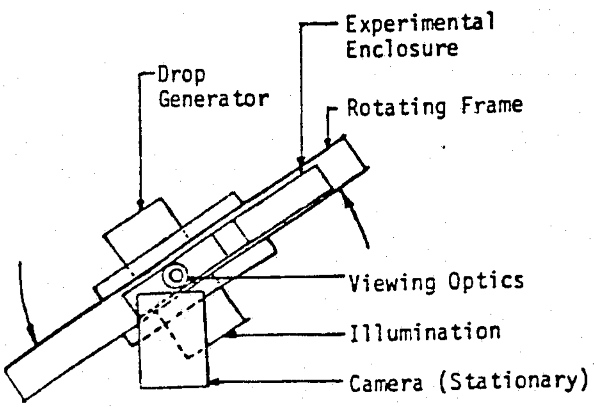

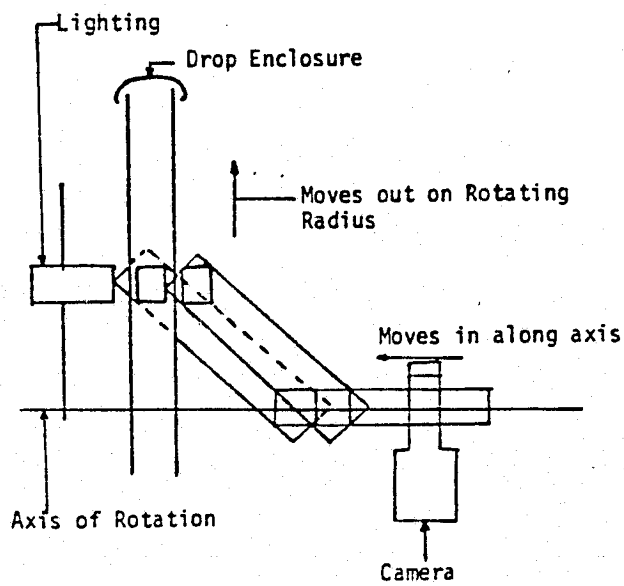

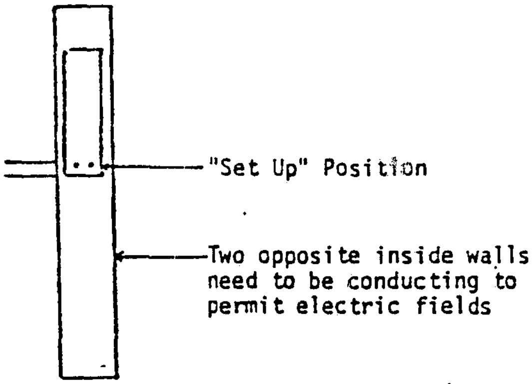

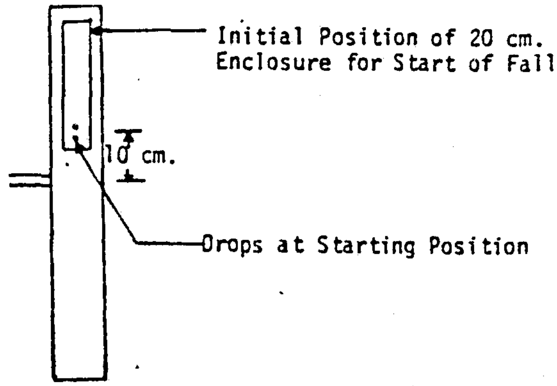

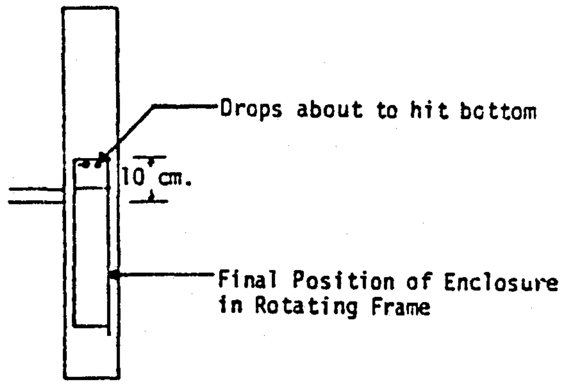

Figures. The figures are self-explanatory and illustrate the experimental apparatus and how the drops are positioned for a collision experiment.

The Figures show the proposed experimental device and how the drops can be viewed while in the rotating experimental space. The optical device proposed would keep the drops central in the field as they were moved radially outwards and remove the rotation from the image. They would be adjusted to their initial positions by acoustic or other methods when in the zero gravitational field on the axis of rotation of the apparatus. Then the tube would be moved radially outwards until the drops were rotating on a 10 cm. radius circle and experiencing the "gravity force" from this centrifugal acceleration. Their position would be maintained at this radius, as they fall, by moving the enclosing tube radially.

The dynamics involved in moving the drops out from the center could be calculated accurately as Stokes' law applies when they are well separated at this stage of their fall. A digital simulator could be put together fairly readily for allowing practice of the setting up procedure.

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APPENDIX 3

Interim Final Report, 15 January 1976

Introduction

This project has as its ultimate goal the study of cloud water droplets to ascertain whether present theory of cloud drop collision and coalescence is adequate. The dynamics of cloud droplets is not yet completely understood. The collisions and interactions that produce rain drops have not proven themselves easy to study. For one thing the droplets are very small, say 20 μm, and small air currents or electric charges affect them greatly. In addition droplets of this size fall at about 1 cm sec^{-1}. This gives the experimenter only seconds to position droplets for an experiment and since the droplets cannot be touched, accurate positioning is impossible in an earth situated laboratory. The possibility of doing experiments in earth orbit eases these problems considerably because the droplets are not falling and so can be positioned by moving the air near them. Furthermore a small simulated and controlled gravity force is possible with a rotating apparatus in which centrifugal force acts like a much lesser gravity than on earth as long as it is needed. With lower gravity applying throughout the collision trajectory it is actually necessary to use larger, more easily controllable droplets. To model the droplets in clouds one must maintain the same dynamical situation. That is, the Reynold's numbers of the droplets used must be the same as those on earth. Analysis shows that this is the requirement that

$$gr^3 = \text{constant}$$

where g is the gravitational acceleration and r is the droplet radius. Thus at a gravity 0.001 of the earth's one may use droplets ten times as large. In addition they would fall only a tenth as fast.

Description of Program to Date

In this project we have begun the study of a system for performing such experiments in orbit. The aim is to produce a system that is mainly self-controlling. Schematically the apparatus consists of a long tube which is rotated about a line perpendicular to its axis. The droplets are injected into the tube and there are subjected to centrifugal force. This provides a controllable amount of "gravity" since the rotation of the tube is by a stepping motor under computer control. Also the tube may be shifted along its length across the axis of rotation. This allows the droplets to be moved from positions near the axis of rotation to positions farther out. At the nearer positions the droplets experience little force and there is more time for the human operator to provide necessary information to the controlling computer. When the droplets are at some distance from the axis of rotation, the tube may be slowly shifted to offset their rotation. This causes the drops to stay at a constant radius and so see a fixed gravity. Eventually the droplets collide with the end of the tube. Thus one must make sure the events of interest can occur within a space limited to a meter or so of total tube length. The actual experimental procedures would be as follows.

The apparatus is provided with an optical system which allows a view of the droplets from above and from the side to facilitate aligning them. A system of prisms removes the rotation so that a stationary observer may view the droplets as if they were fixed. Two droplets are injected into the tube. They are aligned along the length of the tube with the larger placed so that it will fall into the smaller. The tube is shifted by the computer to place the droplets at the desired radius. Then the droplets are held at that radius until the one goes by the other or the end of the tube is reached.

The injection of the droplets is not precisely controllable. There will be random variations in the droplets' positions and variations in the size of the droplets. Thus the drops must be aligned each time. Also one must discover which droplet is heavier to do the alignment correctly. When the droplets are held at a fixed radius, one must shift the tube at a precise rate which depends on the size of the droplet. Fortunately, the radius determination may be made part of the process of alignment. The droplets' own response to manipulations of the apparatus gives away its radius.

Two methods have been used to manipulate the droplets: viscous drag to rotate the droplets' positions and shifts of the tube along its length to move the droplets from one place to another. If the rotational rate of the apparatus is changed, the air within reacts variously depending on position. Far from the axis of rotation the air simply follows the motion of the tube as if it were rigidly connected. (There is a small shift in which barostatic pressure changes in accordance with "gravity"; but this is very small in the cases considered here.) Near to the axis the tube can only act indirectly on the air through viscous drag. The air gradually reaches the new angular velocity through the relatively weak viscous forces. The scale of distances here is provided by the diameter of the tube. "Near" means less than the tube radius and "far" means more than a few radii. In practice a movable "squirrel cage" would be used. This would be a rotatable cylinder that could be moved in and out of the tube with minimal disturbance to the droplets. It would be rotated until the droplets had been turned far enough, stopped and then extracted from the tube. Two of these situated at right angles would be necessary to align the droplets one above the other. An apparatus of this type would have to be calibrated "in flight". It would be difficult to estimate beforehand the rate at which a wire squirrel cage transfers its rotation to the enclosed air. Except for this undetermined parameter the situation is remarkably simple. If one looks at the air long after the rotation of the cage has been stopped, one sees that the air has rotated as a solid body. (This follows mathematically from the linearity of the equations.)

The droplets do not exactly follow the motion of the air but tend to fly out from the center. This depends on the droplet radius, and hence may be used to estimate the radius. One need only measure the distance from the center of rotation before and after the cage has been spun. One may then give a radius estimate without having to know exactly how the cage was spun, for how long, etc. Unfortunately this measurement is sensitive to errors in measurement and care must be used in applying it.

The second maneuver available is shifting the tube along its length. This is necessary for moving the droplets from the center where they are aligned out to the position where they are allowed to collide. One uses it to hold the droplets at the chosen distance while they fall and to help center the droplets in the tube while they are being aligned. An additional use is in gaining radius estimates. One shifts the droplets to a distance from the center, leaves them there while the apparatus rotates, and returns to the center. The amount that the droplets shift depends on the radius and so gives an estimate. At this point one may discover that one has set the heavier droplet below the heavier and the squirrel cage must be used to reverse them. One may also have to abandon the droplets in favor of a new pair. If the droplets are nearly equal in radius while being relatively far apart, the lighter one can fall faster than the heavier because it feels more gravity, being farther from the axis of rotation. Also collision may not occur until after the droplets have reached the end of the tube.

A program has been written which simulates the operation of the experiment. It consists roughly of two parts. One part picks droplets of random size and places them randomly about a point in the tube. This simulates the drops from the droplet generator. The droplet generator can be a vibrating needle from which charged drops are extracted from the droplet stream by an electric field. When a droplet is needed the charging mechanism is turned off and the neutral drop traverses the field region to enter the tube. The program then simulates the actual response of the droplets to manipulating the apparatus. The second part, and only part that would actually be flown with the instrument, starts with the nominal radius of the droplets. It does its own simulations and runs the droplets through the same maneuvers using the estimated droplet size. It uses the differences between the "real" and the simulated drops to estimate the radii. It aligns the droplets and indicates whether the droplets can be run to a collision encounter within the confines of the apparatus after each spin of the squirrel cage, shift of the tube, etc. In this simulation the operator is given a display of the position of the droplets on a CRT and must indicate to the computer the positions of the droplets by adjusting the crosshairs on the screen to coincide with a drop just as he would through using the optical system of the actual experiment. These are the only responses required of the operator. The rest of the decisions are made by the computer.

This current version runs using the University of Nevada timesharing system but is very slow as timeshared intervention is needed repeatedly and the transmission rate is too slow. It does not provide a view of things as they happen. It is only feasible to display the positions of the droplets when a response is needed from the operator.

It is planned for the future that a version will be produced which runs on a minicomputer. When certain hardware enhancements are installed it is hoped that this version will run at nearly real time giving continuous real time simulation. This will provide needed experience to assess the ability of the operator to provide responses quickly enough and accurately enough to operate the experiment. This stage should also show any problems not anticipated at this stage.

Summary

The simulation experiment has progressed to the stage where most of the conceptual problems have been sorted out. The next phase is to implement the simulation in real time to show better the practical aspects of the experiment.

APPENDIX 4

Monthly Progress Report, 17 February 1976

Monthly Progress Report

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center,
Alabama 35812

CONTRACT NUMBER:	NAS8-31441
TITLE OF CONTRACT:	Preparatory Studies for Zero-g Cloud Drop Coalescence Experiment
CONTRACTOR:	Desert Research Institute Energy & Atmospheric Environment Center University of Nevada System SAGE Bldg., Stead Campus Reno, Nevada 89507
PRINCIPAL INVESTIGATOR:	James W. Telford
MONTHLY PROGRESS REPORT NO.:	8
REPORT FOR THE PERIOD:	December 21, 1975 to January 20, 1976
DATE OF THIS REPORT:	February 17, 1976
AUTHOR:	T. S. Keck

1. Progress during the reporting period

During this month the software for simulating the motion of water droplets in a rotating reference frame with air motion was written. This is general enough to be used in all the cases needed. It was applied to the case motion inside a spinning "squirrel cage". Also added this month was the ability to produce hard copies of the CRT displays. This includes software for drawing lines and points plus character generating software for reproducing the labels from the CRT displays. Included with this report are two plots used to help verify the software. Figure 1 shows motion of the droplets when the squirrel cage is turned once and stopped, and Figure 2 gives the motion for one half revolution.

The squirrel cage (not shown) rotates about the point in the center. The position of each droplet is shown each 1/6 second and every one second a line is drawn between the two droplets to clarify their relative positions. This illustrates how the air follows the spinning motion of the squirrel cage only after some delay. The inner droplet does not move much until after the first second. It continues to move for several seconds after the cage has stopped. It may be shown that the air will rotate just as far as the cage. If the cage is rotated one turn, the air after lagging behind will end up moving exactly one revolution when sufficient time has elapsed for the motion to come to rest again. This is not true for the droplets. Note that the angle of lag is bigger for the outer droplet.

There is also considerable radial motion, especially in the 360° case. The algorithm for aligning the drops uses rotations mainly less than 90° where these effects are smaller. Also it spaces the droplets so that they are at the same radius and the centrifugal forces act equally. So the main effect is that one underestimates the angle the squirrel cage should be turned. This was not compensated for in the earlier time-sharing version of the program. It often increased the number of steps to align the droplets. Compensation will only be added to the current program if it seems necessary later on.

This motion provides the initial basic maneuver to adjust two drops which are injected into the tunnel at close but random separations. This maneuver enables the vertical alignment (relative to the radial center line of the rotating tube) to be changed predictably and at will. The aim of the experiment is to produce two drops of measured size in the centrifugal force field at about 10 cm from the axis of rotation. These drops need to have a known separation along the centrifugal force direction and a known sideways separation of a fraction of a drop diameter. The operator will then need to note if coalescence occurs when the bigger drop catches up with the smaller one. This stage of the model is aimed at simulating the initial plans for lining up the drops and determining their sizes.

The early stage in the proposed experiment can be well represented mathematically but the final stage when the drops are less than one diameter apart needs to be verified against the sophisticated numerical treatments available, because of its vital importance in rain formation processes in the atmosphere. Other physical effects such as the role of surface phenomenon in the final stages before contact between the drops can be checked in the actual experiment by using water containing surface active agents, and drops formed from non-polar fluids other than water.

Once a viable set of maneuvers has been generated in this simulation the final specification of the software will enable the space vehicle software to be written without regard to the problems of cloud microphysics which dominate this feasibility and design stage.

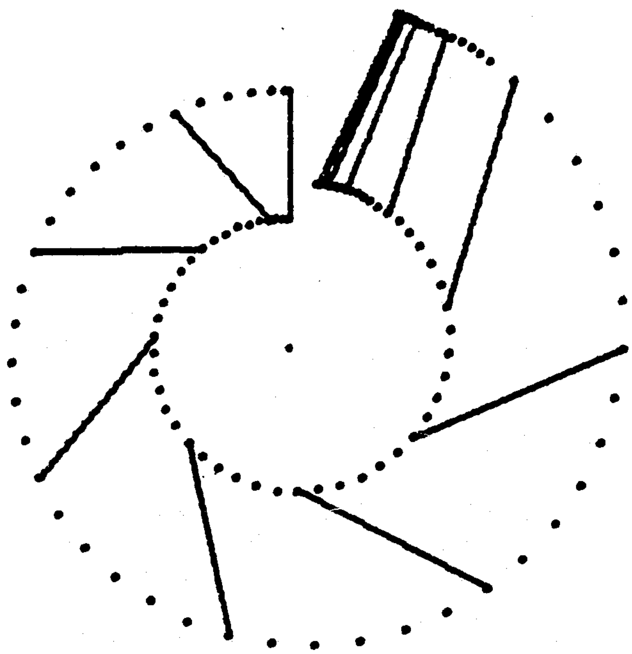

Fig. 1. Motion of droplets within "squirrel cage" rotated 360° and stopped. Position shown at 1/6 second intervals and line drawn between droplets once per second. (Squirrel cage not shown.)

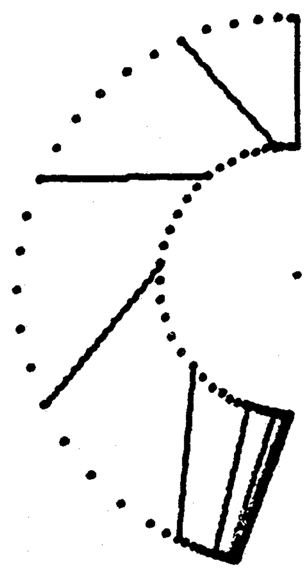

Fig. 2. Same as Fig. 1 with rotation of 180°.

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APPENDIX 5

Monthly Progress Report, 15 March 1976

Monthly Progress Report

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center,
Alabama 35812

CONTRACT NUMBER:	NAS8-31441
TITLE OF CONTRACT:	Preparatory Studies for Zero-g Cloud Drop Coalescence Experiment
CONTRACTOR:	Desert Research Institute Energy & Atmospheric Environment Center University of Nevada System SAGE Bldg., Stead Campus Reno, Nevada 89507
PRINCIPAL INVESTIGATOR:	James W. Telford
MONTHLY PROGRESS REPORT NO.:	9
REPORT FOR THE PERIOD:	January 21, 1976 to February 20, 1976
DATE OF THIS REPORT:	March 15, 1976
AUTHOR:	T. S. Keck

1. Progress during the reporting period

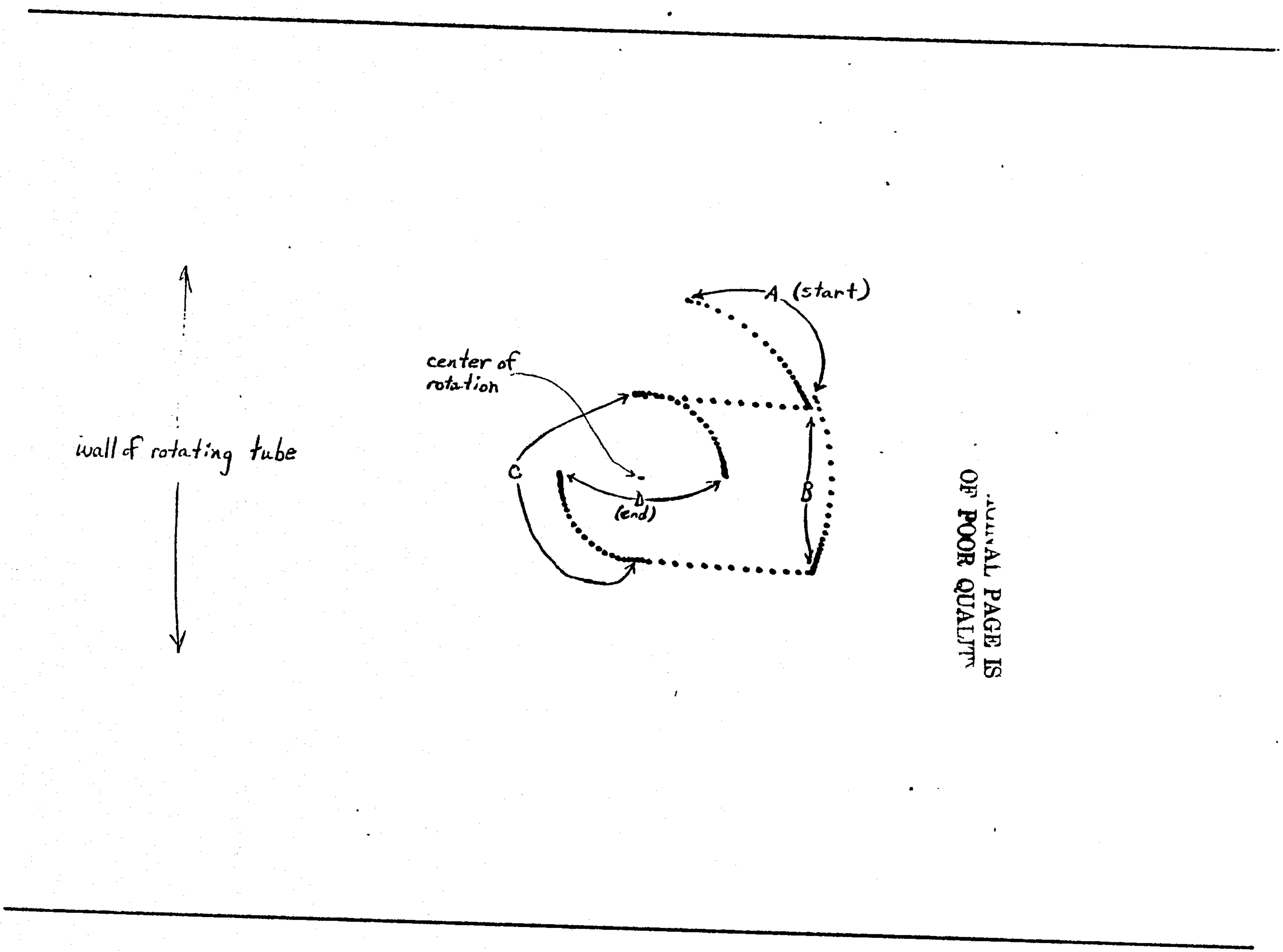
This month the problem of aligning water droplets in the zero-gravity chamber was addressed. Certain refinements were made in the alignment algorithm.

Last month there were included with the report figures showing the affect of rotating a "squirrel cage" about the two droplets. One effect noticed was that the droplets moved through a smaller angle than the squirrel cage. From several numerical experiments a simple correction procedure was derived to predict just how far a given droplet would turn. This procedure was added to the alignment algorithm previously used. There was a great enhancement. Alignments normally took four to six motions. Now two are usually all that are needed.

Included with this report is a plot generated during program execution. This shows the process of alignment of two droplets. The viewpoint is that of an observer rotating with the tube. The center of rotation for both the tube and squirrel cage is marked in the center. The droplets start at the positions marked "A" and their positions are shown thereafter at 1/6 second intervals. The droplets started at the randomly chosen points A. It is desired to bring them to a new position elong the center line of the tube straddling the center of rotation. First the squirrel cage is rotated to make the droplets straddle the center line. They end up at B. Then the whole tube is shifted left to place the center of rotation on the line segment joining the two droplets. The resulting position is C. Finally the squirrel cage is rotated to place the heavier droplet to the left of the other. (Currently this decision is made using the actual size of the droplets. The radius-determining algorithms have not been implemented yet.) The final result is positions D which are close to what was desired.

2. Plans for the next reporting period

In the next month the droplet-radius determining procedures will be added. It is hoped to have hardware then to run the displays at full speed.


A (start)
center of rotation
wall of rotating tube
C
B
D (end)

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APPENDIX 6

Monthly Progress Report, 1 June 1976

Monthly Progress Report

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center,
Alabama 35812

CONTRACT NUMBER:	NAS8-31441
TITLE OF CONTRACT:	Preparatory Studies of Zero-g Cloud Drop Coalescence Experiment
CONTRACTOR:	Desert Research Institute Energy & Atmospheric Environment Center University of Nevada System SAGE Bldg., Stead Campus Reno, NV 89507
PRINCIPAL INVESTIGATOR:	James W. Telford
MONTHLY PROGRESS REPORT NO:	12
REPORT FOR THE PERIOD:	April 21, 1976 to May 20, 1976
DATE OF THIS REPORT:	June 1, 1976
AUTHOR:	T. S. Keck

1. Progress during the reporting period

In this report it would seem opportune to present the mathematical basis for the work under way. We will present the equations used in the numerical simulations. We assume that the small droplets obey Stokes' Law as they fall through the air, i.e. they feel a force

$$\vec{F} = -6\pi\eta r(\vec{v}-\vec{v}_{air})$$

where η = dynamic viscosity of air

r = droplet radius

$\vec{v}_{air}$ = air velocity

Relative to the rotating experimental chamber we then have the equation of motion,

$$\frac{\partial \vec{v}}{\partial t} = -2\vec{\omega} \times \vec{v} + \omega^2 \vec{R} - \frac{6\pi\eta r}{m}(\vec{v}-\vec{v}_{air})$$

$$\kappa = \frac{6\pi\eta r}{m} = \frac{6\pi\eta r}{4/3\ \pi\rho r^3} = \frac{9\eta}{2\rho r^2}$$

where $\vec{\omega}$ = angular velocity vector of rotating system

$\vec{R}$ = radius vector of droplet

ρ = density of water (reduced by density of air)

U = x velocity droplet

V = y velocity droplet

U_a = x velocity air

V_a = y velocity air

Then using a difference approximation of

$$\frac{\partial U}{\partial t} = \frac{1}{t}\left\{U(t+\Delta t)-U(t)\right\}, \text{ etc.}$$

$$U(t+\Delta t) = (1-\kappa\Delta t)U + 2\omega\Delta tV + \omega^2 x\Delta t + \kappa\Delta tU_a$$

$$V(t+\Delta t) = -2\omega\Delta tU + (1-\kappa\Delta t)V + \omega^2 y\Delta t + \kappa\Delta tV_a$$

$$x(t+\Delta t) = x + \Delta t\left\{U(t+\Delta t)+U\right\}/2$$

$$y(t+\Delta t) = y + \Delta t\left\{V(t+\Delta t)+V\right\}/2$$

These equations will be numerically stable if all coefficients are less than 1 in magnitude. This is satisfied if

$$\Delta t < \frac{2}{\kappa} = \frac{4r^2}{9\eta} \quad \text{and} \quad \Delta t < \frac{1}{2\omega}$$

These equations give the motion in all the cases needed to simulate the motion of the droplets. When the tube enclosing the droplets is shifted they feel an air velocity in the direction of movement. The shock waves in air set up by starting the tube into motion, etc. occur on a time scale much less than the reaction of the droplets to Stokes' force and we may simply assume that the air follows the motion of its enclosure.

The other case this equation needed was for motion in a rotating cylinder or "squirrel cage". Here we must integrate the air motion separately. Radial centrifugal effects are small and are dropped. Starting with the Navier-Stokes equation in a rotating frame

$$\frac{d\vec{v}}{dt} = -2\vec{\omega}\times\vec{v} + \omega^2\vec{R} - \frac{1}{p}\nabla p - \nu\nabla\times\nabla\times\vec{v}$$

and dropping all terms in the radial direction, we have

$$\frac{\partial\Omega}{\partial t} = \nu\left(\frac{3}{r}\frac{\partial\Omega}{\partial r} + \frac{\partial^2\Omega}{\partial r^2}\right)$$

where Ω = angular velocity of air

ν = kinematic viscosity of air

Applying a difference approximation we obtain

$$\Omega_i(t+\Delta t) = \left(1 - \frac{2\nu\Delta t}{\Delta r^2}\right)\Omega_i + \frac{\nu\Delta t}{\Delta r^2}\left[\left(1 + \frac{3}{2(i-1)}\right)\Omega_{i+1} + \left(1 - \frac{3}{2(i-1)}\right)\Omega_{i-1}\right]$$

where $r_i = \Delta r(i-1)$

$\Omega_i = \Omega(r_i,t)$

Numerical stability will be obtained if all coefficients are less than 1 in magnitude. This holds if

$$\Delta t < \frac{2}{5}\frac{\Delta r^2}{\nu}$$

This is more restrictive than the limits on Δt given for the droplet motion equations. When simulating the motion of the droplets in the rotating cylinder, the air velocity is calculated from the above equation by interpolation.

When one is using the rotating cylinder to align the droplets, there are precise angles through which the droplets must turn. The air inside acts like it is elastically connected to the cylinder. When the cylinder is rotated through a fixed angle, the air inside eventually stops after going through the same angle. The droplets lag behind the air and do not travel as far. By numerical experiment it was found that a linear correction factor would compensate quite nicely.

$$\theta_{desired} = (1-0.06R)\theta_{required}$$

where R = distance of droplet from axis of rotation

$\theta_{desired}$ = angle that droplet is to turn

$\theta_{required}$ = angle that cylinder must be turned

When two droplets must be positioned, it is sufficient to use the radius of a point midway between them. To estimate the radius of a droplet one takes the droplet motion equation and assumes that the radial component of acceleration is small. (Not true when the appratus is shifted relative to the axis of rotation, but good enough otherwise.) This reduces the equation to

$$\dot{R} = \frac{2\rho r^2 \omega^2 R}{9\eta},$$

notation as before, except that here ω is the total angular velocity of the droplet.

Let $$\Omega(t) = \int_0^t \omega^2(t)\,dt$$

then $$R = R_0 e^{\frac{2\rho\Omega(t)r^2}{9\eta}}$$

Suppose the droplet has a true radius of r_a, but one has estimated the radius to be r_e. If the predicted position is not too different from the actual position, the two values for $\Omega(t)$ will be about the same and one may eliminate it from the two equations for R. This gives

$$\left(\frac{r_a}{r_e}\right)^2 = \frac{\log R_a - \log R_0}{\log R_e - \log R_0}$$

where R_0 = initial position of droplet

R_e = predicted position

R_a = actual position

Some care must be given in using this formula. If the droplets are allowed to drift too far, the correction will not be too accurate, but will still adjust in the correct direction. If insufficient drift has been allowed, then errors in measuring R_a becomes important. In fact small random errors could give wildly different estimates. In the program R_a is shifted by the probable error and if too great a change in the radius correction results, no estimate is made.

During this month work was done to debug the droplet radius estimation procedures. This is not yet complete. Also considered were procedures to compensate for the effects of coriolis force on droplet alignment. This becomes significant when droplets are shifted from a point near the axis of rotation out to the position where they are to collide.

This month the effects of coriolis force on the relative alignment were simulated. To study the dynamics of collisions one must align the droplets quite closely. On moving droplets from near the center of rotation out to an appreciable radius, coriolis force changes the alignment. Thus it is necessary to compensate for this by adjusting the alignment before moving the droplets out to the fixed radius. Simulations of this were done using the University of Nevada CDC timesharing system.

Work on this project has come to a halt waiting for the return of the MAC-16 computer and the start of the next contract period.

2. Plans for the next reporting period

Little work on the MAC-16 minicomputer programs may be done in the next month because the computer has been returned to the factory for hardware improvements. Included is high-speed interface for the CRT and wiring for a set of multiplexer data channels. The data channels themselves are not being purchased at this time.

APPENDIX 7

Monthly Progress Report, 1 July 1977

Monthly Progress Report

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center,
Alabama 35812

CONTRACT NUMBER:	NAS8-31441
TITLE OF CONTRACT:	Preparatory Studies of Zero-g Cloud Drop Coalescence Experiment
CONTRACTOR:	Desert Research Institute Energy & Atmospheric Environment Center University of Nevada System P. O. Box 60220 Reno, NV 89506
PRINCIPAL INVESTIGATOR:	James W. Telford
MONTHLY PROGRESS REPORT NO:	24
REPORT FOR THE PERIOD:	April 21, 1977 to May 20, 1977
DATE OF THIS REPORT:	July 1, 1977
AUTHOR:	T. S. Keck

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1. Progress during the reporting period

Work continued on the predicter formulas. These give the procedure for moving a pair of droplets from their initial positions to the location for the desired collision. So far it has been assumed that the droplets have radii of 33 μm and 35 μm. A set of third order least square fit formulas was produced (three formulas with all terms to the third order in the four initial position coordinates). These formulas worked well over a wide range of initial positions. The errors tended to have the same sense for both droplets. Collisions did not occur exactly at the target position, but they did occur, and were near the target.

The formulas are extremely unwieldy. The 105 coefficients would become 525 if the size of the droplets were allowed to vary and terms only to the second order in droplet radius were retained. The formulas represent a large amount of computation. Solutions are obtained over the whole range of circumstances that may occur. Then the least square procedure compresses this into a form that requires much less computing to evaluate (even with 500+ coefficients!). Another approach would be to do some of this computation in flight. A simpler set of prediction formulas would be used to obtain rough values for the alignment. Once the computer has determined values for the droplet radii, it could then proceed to compute more accurate values over a small range of droplet positions. This could be "in the background" with results only needed in the final stages of the operations. The computer would proceed to move the droplets into positions near those for which it is determining values. An interpolation would then give the information needed to effect the droplet collision.

2. Plans for the next reporting period

In the next reporting period the details of this on-board computation procedure will be proved further.

APPENDIX 8

Monthly Progress Report, 7 July 1977

Monthly Progress Report

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center,
Alabama 35812

CONTRACT NUMBER:	NAS8-31441
TITLE OF CONTRACT:	Preparatory Studies of Zero-g Cloud Drop Coalescence Experiment
CONTRACTOR:	Desert Research Institute Energy & Atmospheric Environment Center University of Nevada System P. O. Box 60220 Reno, NV 89506
PRINCIPAL INVESTIGATOR:	James W. Telford
MONTHLY PROGRESS REPORT NO.:	25
REPORT FOR THE PERIOD:	May 21, 1977 to June 20, 1977
DATE OF THIS REPORT:	July 7, 1977
AUTHOR:	T. S. Keck

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1. Progress during the report period

In this month an improved procedure for determining droplet radii was developed. This was developed from a closed-form solution to the equation for droplet motion in still air.

If the air is still in a rotating frame of reference the equations of motion of a droplet are

$$\frac{d^2x}{dt^2} = 2\omega \frac{dy}{dt} + \omega^2 x - k \frac{dx}{dt}$$

$$\frac{d^2y}{dt^2} = -2\omega \frac{dx}{dt} + \omega^2 y - k \frac{dy}{dt}$$

where (x,y) is droplet position

ω is angular velocity of frame

k is given by Stokes' Law as $\frac{9\eta}{4r^2}$

η is viscosity of air

r is droplet radius

Let $z = x+iy$. Then, $\frac{d^2z}{dt} = -(k+2\omega i)\frac{dz}{dt} + \omega^2 z$

with general solution,

$$z(t) = A \exp(\frac{-\alpha+\beta}{2} t) + B \exp(\frac{-\alpha-\beta}{2} t)$$

$$A = \frac{1}{\beta}(u_0+\frac{\alpha+\beta}{2} z_0)$$

$$B = -\frac{1}{\beta}(u_0+\frac{\alpha-\beta}{2} z_0)$$

$$\alpha = k+2\omega i$$

$$\beta = (k^2+4\omega i)^{\frac{1}{2}}$$

$$z_0 = z(0)$$

$$u_0 = \frac{dz}{dt}(0)$$

Transients die out quite rapidly with a time constant of about 40. So we may take $B = 0$. Then

$$z(t) = z_0 \exp(\frac{-\alpha+\beta}{2} t)$$

This shows how unimportant the process is of injecting the droplets into the chamber. Only the position that this leaves the droplets matters. Separately the real and imaginary parts

$$\delta + \varepsilon i = \frac{-\alpha+\beta}{2}$$

$$x(t) = (x_0\cos\varepsilon t - y_0\sin\varepsilon t)e^{\delta t}$$

$$y(t) = (y_0\cos\varepsilon t + x_0\sin\varepsilon t)e^{\delta t}$$

$$R(t) = (x^2+y^2)^{\frac{1}{2}} = R(0)e^{\delta t}$$

Thus the radius vector of the droplet increases exponentially. Evaluating for δ,

$$\delta = \frac{\omega^2}{k} - \frac{5\omega^4}{k^3} + \frac{42\omega^6}{k^5} - \ldots$$

reverting the series,

$$\frac{1}{k} = \frac{\delta}{\omega^2}(1+5\frac{\delta^2}{2} + 33\frac{\delta^4}{\omega^4} + \ldots)$$

$$r^2 \simeq \frac{9\eta\delta}{4\omega^2}(1+5\frac{\delta^2}{\omega^2})$$

$$(33\frac{\delta^4}{\omega^4} < 5x10^{-4})$$

Thus the radial motion of the droplet gives the radius of the droplet through a simple formula. In practice one can determine δ by performing a least-square fit from several positions of the droplet.

The solution of the droplet equation will be very useful to the simulation programs, which are still needed when the air is in motion. For example, the condition B = 0 gives,

$$u_0 = \frac{-\alpha+\beta}{2} z_0 = (\delta+\varepsilon i)z_0,$$

i.e. an initial velocity for any given initial position.

2. Plans for the next reporting period

In the next month these results will be used in the further development of a scheme for affecting droplet collisions.

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APPENDIX 9

Monthly Progress Report, 15 March 1978

Monthly Progress Report

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center,
Alabama 35812

CONTRACT NUMBER:	NAS8-31441
TITLE OF CONTRACT:	Preparatory Studies of Zero-g Cloud Drop Coalescence Experiment
CONTRACTOR:	Desert Research Institute Atmospheric Sciences Center P. O. Box 60220 Reno, NV 89506
PRINCIPAL INVESTIGATOR:	James W. Telford
MONTHLY PROGRESS REPORT NO.:	30
REPORT FOR THE PERIOD:	October 21, 1977 to November 20, 1977
DATE OF THIS REPORT:	March 15, 1978
AUTHOR:	T.S. Keck

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1. Progress during the report period

One part of the control of this experiment has proved quite complicated. This is positioning a pair of droplets so that they will collide at the desired place. It is complicated by the rotation of the apparatus. Falling droplets are forced sideways as they move by Coriolis force. One must compensate before hand for this with a small shift to the opposite side. Accurately predicting this small shift has been a problem. Given unlimited computation time, this could be solved by trial and error. This can be stated as the following: The droplets are at A and B at present time. Find operations that result in their collision near C at a later time. Each guess requires a simulation run to determine if it works. This requires time which eventually runs out since the droplets continue to move as computations go on. One solution that was tried was to do all the computation ahead of time. Many simulations were done for representative situations and then a least-square fit was done to fill in the gaps. This proved unworkable when a sixth degree polynomial in six variables was inadequate. At this time an intermediate solution seems workable. When the representative solutions for the least-square fit were generated, a successive approximation method was used. Convergence was quite fast (2 or 3 trials) once an approximate solution was found. Thus, for the real-time case, the approximating polynomial need only be accurate enough to come into the useful range of the interative technique.

The following procedure is being investigated. One predicts the droplet positions at a time far enough ahead to do, say, five complete simulations. The predicted position is substituted into a polynomial formula to obtain a trial solution. The trial solution is interated upon until either it converges or time runs out.

2. Plans for the next reporting period

In the next month approximating procedures will be investigated further.

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Appendix 10

Mini-Computer (MAC 16) Coding

```
               +*   DROPLET SIMULATOR
               +       ENTRY CALCOMP
               +       ENTRY DECOUT
               +       ENTRY MODE,QMODO,GINI,RDCORD
               +       ENTRY PAK.PKP
               +       ENTRY MSG.ESCENQ
               +       ENTRY LOG2
               +       ENTRY XOFF,YOFF,SCALE
               +*
               +       EXTRN PLOT,SYMBOL
               +       EXTRN FNEG,FRACT
               +       EXTRN FMUL,FADD,FSUB,FDIV,NORM,FLOAT.FIX
               +       EXTRN XPOS,YPOS
               +       EXTRN XLOC,YLOC,MARK
               +       EXTRN CRT,PKP1,BLEN2
               +       EXTRN MOVE
               +       EXTRN TRIG,SIN.COS
               +       ORG $800
0800 0481+TURN  SKP 1
0801 5000+      JMP MIZL
0802 0501+      SEX H
0803 0D04+      LDI 4   TURN OFF TTY INTERRUPTS
0804 0F46+      FCO 4,6
0805 5204+      JMP *-1
0806 C001+      LDX =$74
0807 D002+       LDA =KLOK
0808 0740+       SAX 0
0809 0540+       CLA
080A 0743+       SAX 3
080B 05C1+      REX H
080C D003+     LDA I11
080D 6004+      STA DR
080E D005+      LDA I11+1
080F 6006+      STA DR+1   DR=1/11
0810 4007+      JMM FMUL
0811 0CFD+      DC DR,DR,WS
0812 0CFD
0813 0D01
0814 D008+      LDA WS
0815 6009+      STA DT
0816 D00A+      LDA WS+1
0817 0801+      ADI 1
0818 600B+      STA DT+1   DT=2DR**2
0819 4007+      JMM FMUL
081A 0CF9+      DC NU,DT,A   A=NU*DT
081B 0CFF
081C 0D23
081D 400C+      JMM FDIV
081E 0D23+      DC A,WS,B   B=A/DR**2
081F 0D01
0820 0D25
0821 D00D+      LDA B
0822 600E+      STA C
0823 D00F+      LDA B+1
0824 0801+      ADI 1
0825 6010+      STA C+1
0826 4011+      JMM FSUB
0827 0D03+      DC D1,C.C   C=1-2B
0828 0D27
0829 0D27
082A D010+      LDA C+1
082B 0901+      SBI 1
082C 6010+      STA C+1
082D 4012+      JMM FRACT
082E 0D27+      DC C       C SCALED @B1
082F D00F+      LDA B+1
0830 0801+      ADI 1
0831 600F+      STA B+1
```

```
0832 4012+      JMM FRACT
0833 0D25+     DC B       B SCALED @B-1 OR 4B @B1
0834 D00E+      LDA C
0835 6013+      STA CR
0836 D00D+     LDA B
0837 6014+     STA BR
0838 400C+     JMM FDIV
0839 0CFF+     DC DT,PI,DROTF
083A 0CEA
083B 0CFC
083C 4007+     JMM FMUL
083D 0CE4+     DC OMEGA.DT,C3
083E 0CFF
083F 0CF5
0840 4007+     JMM FMUL
0841 0CE4+     DC OMEGA,C3,C4
0842 0CF5
0843 0CF7
0844 4015+     JMM TWICE
0845 0CF5+     DC C3
0846 4007+     JMM FMUL
0847 0CE4+     DC OMEGA.OMEGA,OMS2
0848 0CE4
0849 0DE7
084A 400C+     JMM FDIV
084B 0CE2+     DC COEF,OMS2,XHCOF
084C 0DE7
084D 0ED2
084E D016+     LDA CALCOMP
084F 04A4+     SAZ 4
0850 4017+     JMM PLOT INITIALIZE PLOTTER
0851 0CE1+     DC FOUR,ONE,-1
0852 0CF0
0853 FFFF
0854 4007+     JMM FMUL
0855 0DD7+     DC M400.,DT,TINC
0856 0CFF
0857 0DD9
0858 4018+     JMM FIX
0859 0DD9+     DC TINC
085A D019+     LDA TINC
085B 601A+     STA TINC+1
085C 52C8+     JMP SKIP
```

```
085D 201B+TUBER STX TURX
085E D01C+      LDA FALL
085F 04A1+      SAZ 1
0860 528D+      JMP HERBST
0861 401D+      JMM MOVE
0862 0DE0+      DC D350.,SCALE
0863 0DE4
0864 401E+      JMM ZERO
0865 0CFF+      DC XOFF,YOFF,0
0866 0CF1
0867 0000
0868 400C+      JMM FDIV
0869 0DF2+      DC D14..SCALE,WIDTH
086A 0DE4
086B 1260
086C 401F+      JMM CRT  DRAW TUBE
086D 0DB3+      DC M1.46.M1.03,4
086E 0DB7
086F 0004
0870 401F+      JMM CRT
0871 0DB5+      DC D1.46.M1.03,2
0872 0DB7
0873 0002
0874 401F+      JMM CRT
0875 0DB5+      DC D1.46.D1.03,4
0876 0DB9
0877 0004
0878 401F+      JMM CRT
0879 0DB3+      DC M1.46.D1.03,2
087A 0DB9
087B 0002
087C 4020+      JMM MSG
087D 0889+      DC PLX,PLY,PLUS
087E 088B
087F 0DD0
0880 4020+      JMM MSG
0881 08C6+      DC M.1,D.1,Z1
0882 08C4
0883 0E02
0884 4020+      JMM MSG
0885 08C4+      DC D.1,D.1,Z2
0886 08C4
0887 0E04
0888 581B+      JMP *TURX
0889 87A1+PLX   DC -.73469E-2B-7,-7
088A FFF9
088B B4C5+PLY   DC -.91836E-2B-6,-6
088C FFFA
         +*
088D D021+HERBST LDA =84B7
088E 6022+      STA SCALE
088F 0D07+      LDI 7
0890 6023+      STA SCALE+1
0891 D024+      LDA =5B3
0892 6025+      STA XOFF
0893 0D03+      LDI 3
0894 6026+      STA XOFF+1
0895 400C+      JMM FDIV
0896 0DF2+      DC D14..SCALE,WIDTH
0897 0DE4
0898 1260
0899 401F+      JMM CRT
089A 08C2+      DC M1.,D1,4
089B 0D03
089C 0004
089D 401F+      JMM CRT
089E 0DA9+      DC D11,D1.2
089F 0D03
```

```
08A0  0002
08A1  401F+       JMM  CRT
08A2  0DA9+       DC D11,D0.0,4
08A3  0DBD
08A4  0004
08A5  401F+       JMM  CRT
08A6  08C2+       DC M1.,D0.0,2
08A7  0DBD
08A8  0002
08A9  401F+       JMM  CRT
08AA  08C2+       DC M1.,M1.,4
08AB  08C2
08AC  0004
08AD  401F+       JMM  CRT
08AE  0DA9+       DC D11,M1.,2
08AF  08C2
08B0  0002
08B1  401F+       JMM  CRT
08B2  0DDB+       DC D10.,D.1,4
08B3  08C4
08B4  0004
08B5  401F+       JMM  CRT
08B6  0DDB+       DC D10.,M.1,2
08B7  08C6
08B8  0002
08B9  401F+       JMM  CRT
08BA  0DBD+       DC D0.0,D1,4
08BB  0D03
08BC  0004
08BD  401F+       JMM  CRT
08BE  0DBD+       DC D0.0,M1.,2
08BF  08C2
08C0  0002
08C1  581B+       JMP *TURX
          +*
08C2  8000+M1.  DC $8000,0
08C3  0000
08C4  6666+D.1   DC .1B-3,-3
08C5  FFFD
08C6  999A+M.1   DC -.1B-3,-3
08C7  FFFD
```

```
                +SKIP LSTSY
08C8  401F+          JMM ZERO
08C9  0D44+          DC U1,V1,U2,V2
08CA  0D46
08CB  0D58
08CC  0D5A
08CD  0D70+          DC EX1,EX2,EY1,EY2
08CE  0D86
08CF  0D72
08D0  0D88
08D1  0CEF+          DC XOFF,YOFF,ANG
08D2  0CF1
08D3  0CF8
08D4  0FD8+          DC UA,VA,VELD,0
08D5  0FDA
08D6  0DE2
08D7  0000
08D8  0540+          CLA
08D9  6027+          STA ESTF1
08DA  6028+          STA ESTF2
08DB  6029+          STA TNXT
08DC  602A+          STA ITIME
08DD  602B+          STA IFPASS
08DE  602C+          STA TEST
08DF  602D+          STA MARK
08E0  0D40+          LDI 64
08E1  602E+          STA GINSW
08E2  602F+          STA PAWS
08E3  D01C+          LDA FALL
08E4  04A1+          SAZ 1
08E5  53AD+          JMP AUTM
08E6  4030+           JMM PICKX
08E7  0D48+           DC X1
08E8  4030+           JMM PICKX
08E9  0D5C+           DC X2
08EA  4030+           JMM PICKX
08EB  0D4A+           DC Y1
08EC  4030+           JMM PICKX
08ED  0D5E+           DC Y2
08EE  4031+           JMM PICKR
08EF  0D56+           DC R1
08F0  4031+           JMM PICKR
08F1  0D6A+          DC R2
08F2  D032+          LDA R0    SET ESTIMATED RADII TO NOMINAL VALUE
08F3  6033+          STA ER1
08F4  6034+          STA ER2
08F5  D035+          LDA R0+1
08F6  6036+          STA ER1+1
08F7  6037+          STA ER2+1
08F8  4038+          JMM XCOFF  CALC INTEGRATION COEFS
08F9  0D44+          DC Q1     FOR PARTICLE 1
08FA  4038+          JMM XCOFF
08FB  0D58+          DC Q2     NO. 2
08FC  4038+          JMM XCOFF
08FD  0D6C+          DC EQ1   PART 1 WITH EST RADIUS
08FE  4038+          JMM XCOFF
08FF  0D82+          DC EQ2   NO. 2
0900  0540+          CLA
0901  6039+          STA VSH
0902  603A+          STA VSH+1
0903  603B+          STA FITTING
0904  603C+          STA MV1
0905  603D+          STA MV2
0906  603E+          STA DID1
0907  603F+          STA DID2
0908  6040+          STA XTIME
0909  0D01+          LDI 1
090A  6041+          STA XRED
```

```
090B 401D+        JMM MOVE
090C 0B5B+        DC D30.,TP
090D 0DAB
090E 4042+        JMM SHIFT  COLLECT CROSSHAIR INPUTS
090F 0540+        CLA
0910 603B+        STA FITTING
0911 603C+        STA MV1
0912 603D+        STA MV2
0913 603E+        STA DID1
0914 603F+        STA DID2
0915 0D01+        LDI 1  DISPLAY RESULTS
0916 4043+        JMM MODE
0917 401F+        JMM CRT
0918 0DB3+        DC M1.46,D.5,4
0919 0DF6
091A 0004
091B 4044+        JMM DECOUT
091C 0D48+        DC X1
091D 4044+        JMM DECOUT
091E 0D4A+        DC Y1
091F 4044+        JMM DECOUT
0920 0D56+        DC R1
0921 401F+        JMM CRT
0922 0DB3+        DC M1.46,D.4,4
0923 0DFC
0924 0004
0925 4044+        JMM DECOUT
0926 0D5C+        DC X2
0927 4044+        JMM DECOUT
0928 0D5E+        DC Y2
0929 4044+        JMM DECOUT
092A 0D6A+        DC R2
092B 401F+        JMM CRT
092C 0DB3+        DC M1.46,M.4,4
092D 0DFF
092E 0004
092F 4044+        JMM DECOUT
0930 0D70+        DC EX1
0931 4044+        JMM DECOUT
0932 0D72+        DC EY1
0933 4044+        JMM DECOUT
0934 0D7E+        DC ER1
0935 401F+        JMM CRT
0936 0DB3+        DC M1.46,M.5,4
0937 0E00
0938 0004
0939 4044+        JMM DECOUT
093A 0D86+        DC EX2
093B 4044+        JMM DECOUT
093C 0D88+        DC EY2
093D 4044+        JMM DECOUT
093E 0D94+        DC ER2
093F 0A47+WESC    EDI 4,7
0940 533F+        JMP *-1  WAIT FOR ESC
0941 091B+        SBI $1B
0942 04A1+        SAZ 1
0943 533F+        JMP WESC
0944 401D+        JMM MOVE
0945 0F39+        DC D.25,VSH
0946 0DD5
0947 4045+        JMM FADD
0948 0D72+        DC EY1,EY2,TP
0949 0D88
094A 0DAB
094B D046+        LDA TP+1
094C 0804+         ADI 4
094D 04D1+         SAG 1
094E 536D+         JMP XTEST
```

```
094F 4045+ALIGN JMM FADD
0950 0D70+       DC EX1,EX2,TP2
0951 0D86
0952 0DAD
0953 4047+        JMM ATAN
0954 0DAB+        DC TP,TP2,THETA
0955 0DAD
0956 0DAF
0957 4048+        JMM FNEG
0958 0DAF+        DC THETA
0959 D049+        LDA THETA+1
095A 0801+       ADI 1
095B 04D1+       SAG 1
095C 5368+       JMP COMPEN
095D D04A+       LDA THETA
095E 04B5+       SAN 5
095F 4011+       JMM FSUB
0960 0DAF+        DC THETA,D1,THETA
0961 0D03
0962 0DAF
0963 5368+       JMP COMPEN
0964 4045+       JMM FADD
0965 0DAF+       DC THETA,D1,THETA
0966 0D03
0967 0DAF
0968 404B+COMPEN JMM RADIUS
0969 0DAB+       DC TP,TP2,TP
096A 0DAD
096B 0DAB
096C 404C+       JMM TWIST
096D 4045+XTEST JMM FADD
096E 0D70+       DC EX1,EX2,TP
096F 0D86
0970 0DAB
0971 D046+       LDA TP+1
0972 0804+       ADI 4
0973 04D1+       SAG 1
0974 537A+       JMP YTEST
0975 404D+       JMM HALF
0976 0DAB+       DC TP
0977 4048+       JMM FNEG
0978 0DAB+       DC TP
0979 4042+       JMM SHIFT
097A 4045+YTEST JMM FADD
097B 0D72+       DC EY1,EY2,TP
097C 0D88
097D 0DAB
097E D046+       LDA TP+1
097F 0804+       ADI 4
0980 04B1+       SAN 1
0981 534F+       JMP ALIGN
0982 D036+       LDA ER1+1
0983 F037+       CAA ER2+1
0984 538C+       JMP IS1
0985 538A+       JMP IS2
0986 D033+       LDA ER1
0987 F034+       CAA ER2
0988 538C+       JMP IS1
0989 0500+       NOP
098A D04E+IS2    LDA =-1
098B 0481+       SKP 1
098C 0D01+IS1    LDI 1
098D 604F+       STA WHICH
098E 4011+       JMM FSUB
098F 0D86+       DC EX2,EX1,TP
0990 0D70
0991 0DAB
0992 4011+       JMM FSUB
```

```
0993 0D72+       DC EY1,EY2,TP2
0994 0D88
0995 0DAD
0996 D04F+       LDA WHICH
0997 04D4+       SAG 4
0998 4048+       JMM FNEG
0999 0DAB+       DC TP
099A 4048+       JMM FNEG
099B 0DAD+       DC TP2
099C 4047+       JMM ATAN
099D 0DAD+       DC TP2,TP,THETA
099E 0DAB
099F 0DAF
09A0 404B+       JMM RADIUS
09A1 0D70+       DC EX1,EY1,TP
09A2 0D72
09A3 0DAB
09A4 4007+       JMM FMUL
09A5 0DAF+       DC THETA,D1.05,THETA
09A6 0DF8
09A7 0DAF
09A8 404C+       JMM TWIST
09A9 0540+       CLA
09AA 6039+       STA VSH
09AB 603A+       STA VSH+1
09AC 53BE+       JMP DOFALL
```

```
09AD E02C+AUTM  INC TEST
09AE 401D+      JMM MOVF
09AF 0CF3+      DC R0,R1
09B0 0D56
09B1 401D+      JMM MOVF
09B2 0CF3+      DC R0,ER1
09B3 0D7E
09B4 401D+      JMM MOVF
09B5 0DE9+      DC R02,R2
09B6 0D6A
09B7 401D+      JMM MOVF
09B8 0DE9+      DC R02,ER2
09B9 0D94
09BA 4038+      JMM XCOFF
09BB 0D44+      DC Q1
09BC 4038+      JMM XCOFF
09BD 0D58+      DC Q2
          +DOFALL LSTSY
09BE 401D+      JMM MOVF
09BF 0D7E+      DC ER1,XP+2
09C0 0B7B
09C1 401D+      JMM MOVF
09C2 0D94+      DC ER2,XP+4
09C3 0B7D
09C4 4007+      JMM FMUL
09C5 0D7E+      DC ER1,ER2,XP+6
09C6 0D94
09C7 0B7F
09C8 4007+      JMM FMUL
09C9 0D7E+      DC ER1,ER1,XP+8
09CA 0D7E
09CB 0B81
09CC 4007+      JMM FMUL
09CD 0D94+      DC ER2,ER2,XP+10
09CE 0D94
09CF 0B83
09D0 4007+      JMM FMUL
09D1 0B63+      DC AP+2,XP+2,AOFF
09D2 0B7B
09D3 0B55
09D4 4007+      JMM FMUL
09D5 0B65+      DC AP+4,XP+4,WS
09D6 0B7D
09D7 0D01
09D8 4045+      JMM FADD
09D9 0D01+      DC WS,AOFF,AOFF
09DA 0B55
09DB 0B55
09DC 4007+      JMM FMUL
09DD 0B67+      DC AP+6,XP+6,WS
09DE 0B7F
09DF 0D01
09E0 4045+      JMM FADD
09E1 0D01+      DC WS,AOFF,AOFF
09E2 0B55
09E3 0B55
09E4 4007+      JMM FMUL
09E5 0B69+      DC AP+8,XP+8,WS
09E6 0B81
09E7 0D01
09E8 4045+      JMM FADD
09E9 0D01+      DC WS,AOFF,AOFF
09EA 0B55
09EB 0B55
09EC 4007+      JMM FMUL
09ED 0B6B+      DC AP+10,XP+10,WS
09EE 0B83
09EF 0D01
```

```
09F0 4045+      JMM FADD
09F1 0D01+      DC WS,AOFF,AOFF
09F2 0B55
09F3 0B55
09F4 4045+      JMM FADD
09F5 0B61+      DC AP,AOFF,AOFF
09F6 0B55
09F7 0B55
09F8 4007+      JMM FMUL
09F9 0B6F+      DC BP+2,XP+2,WS
09FA 0B7B
09FB 0D01
09FC 4045+      JMM FADD
09FD 0B6D+      DC BP,WS,ASLOPE
09FE 0D01
09FF 0B53
0A00 4007+      JMM FMUL
0A01 0B71+      DC BP+4,XP+4,WS
0A02 0B7D
0A03 0D01
0A04 4045+      JMM FADD
0A05 0D01+      DC WS,ASLOPE,ASLOPE
0A06 0B53
0A07 0B53
0A08 4007+      JMM FMUL
0A09 0B73+      DC BP+6,XP+6,WS
0A0A 0B7F
0A0B 0D01
0A0C 4045+      JMM FADD
0A0D 0D01+      DC WS,ASLOPE,ASLOPE
0A0E 0B53
0A0F 0B53
0A10 4007+      JMM FMUL
0A11 0B75+      DC BP+8,XP+8,WS
0A12 0B81
0A13 0D01
0A14 4045+      JMM FADD
0A15 0D01+      DC WS,ASLOPE,ASLOPE
0A16 0B53
0A17 0B53
0A18 4007+      JMM FMUL
0A19 0B77+      DC BP+10,XP+10,WS
0A1A 0B83
0A1B 0D01
0A1C 4045+      JMM FADD
0A1D 0D01+      DC WS,ASLOPE,ASLOPE
0A1E 0B53
0A1F 0B53
0A20 400C+      JMM FDIV
0A21 0D4C+      DC C11,DT,KA
0A22 0CFF
0A23 0DDE
0A24 400C+      JMM FDIV
0A25 0D60+      DC C21,DT,KB
0A26 0CFF
0A27 0DE0
0A28 400C+      JMM FDIV
0A29 0DE7+      DC OMS2,KA,KA
0A2A 0DDE
0A2B 0DDE
0A2C 400C+      JMM FDIV
0A2D 0DE7+      DC OMS2,KB,KB
0A2E 0DE0
0A2F 0DE0
0A30 4007+      JMM FMUL
0A31 0DDE+      DC KA,D10.,VFLD
0A32 0DDB
0A33 0DE2
```

```
0A34 4048+       JMM FNEG
0A35 0DF2+       DC VELD
0A36 4007+       JMM FMUL
0A37 0B59+       DC M10.,KA,LVEL
0A38 0DDE
0A39 0B5F
0A3A 400C+       JMM FDIV
0A3B 0B5B+       DC D30.,DT,LWHILE
0A3C 0CFF
0A3D 0B5D
0A3E 4018+       JMM FIX
0A3F 0B5D+       DC LWHILE
0A40 4047+       JMM ATAN
0A41 0B41+       DC OSLOPE,D1,TP
0A42 0D03
0A43 0DAB
0A44 4011+       JMM FSUB
0A45 0DAB+       DC TP,M.25,SAXON
0A46 0B45
0A47 0B49
0A48 4050+       JMM SQRT
0A49 0B4D+       DC D2.,TP2
0A4A 0DAD
0A4B 4011+       JMM FSUB
0A4C 0D03+       DC D1,OSLOPE,TP
0A4D 0B41
0A4E 0DAB
0A4F 400C+       JMM FDIV
0A50 0DAD+       DC TP2,TP,TP2
0A51 0DAB
0A52 0DAD
0A53 4007+       JMM FMUL
0A54 0DAD+       DC TP2,OOFF,DST2
0A55 0B43
0A56 0B4B
0A57 D357+       LDA TEST
0A58 04A1+       SAZ 1
0A59 5271+       JMP AGAIN
0A5A 0D01+       LDI 1
0A5B 601C+       STA FALL
0A5C 4043+       JMM MODE
0A5D 4051+       JMM WIPE
0A5E 4052+       JMM TUBER
0A5F 4011+       JMM FSUB
0A60 0D5C+       DC X2,X1,WS
0A61 0D48
0A62 0D01
0A63 D008+       LDA WS
0A64 04D1+       SAG 1   MAKE X1 THE DOWNWARD DROP
0A65 52A8+       JMP ACTION
0A66 C053+       LDX =-14
0A67 D454+       LDA Q1+14,1
0A68 6008+       STA WS
0A69 D455+       LDA Q2+14,1
0A6A 6454+       STA Q1+14,1
0A6B D008+       LDA WS
0A6C 6455+       STA Q2+14,1
0A6D 0201+       INX 1
0A6E 5267+       JMP *-7
0A6F 52A8+       JMP ACTION
0A70     +       DS 1    SPACER
0A71 0D01+AGAIN LDI 1
0A72 4043+       JMM MODE
0A73 0540+       CLA
0A74 6008+       STA WS
0A75 600A+       STA WS+1
0A76 6056+       STA Y1
0A77 6057+       STA Y1+1
```

```
0A78 6358+      STA IFPASS
0A79 601C+      STA FALL
0A7A 4052+      JMM TUBFR
0A7B E01C+      INC FALL
0A7C 401D+      JMM MOVF
0A7D 0B37+      DC POS1,X1
0A7E 0D48
0A7F 0D8D+      LDI $8D
0A80 4058+      JMM PAK
0A81 430F+      JMM LOCATF  SET FIRST DROPLET POSITION
0A82 0D48+      DC X1,Y1
0A83 0D4A
0A84 430F+      JMM LOCATF
0A85 0B4B+      DC DST2,WS     DISTANCE TO SHIFT TUBE
0A86 0D01
0A87 401D+      JMM MOVF
0A88 0DBD+      DC D0.0,X2
0A89 0D5C
0A8A 401D+      JMM MOVF
0A8B 0DBD+      DC D0.0,TP
0A8C 0DAB
0A8D 430F+      JMM LOCATF
0A8E 0D5C+      DC X2,TP
0A8F 0DAB
0A90 0D01+      LDI 1
0A91 4043+      JMM MODF
0A92 4051+      JMM WIPF
0A93 F01C+      INC FALL
0A94 4052+      JMM TUBFR
0A95 4045+      JMM FADD
0A96 0D03+      DC D1,TP,TP
0A97 0DAB
0A98 0DAB
0A99 4007+      JMM FMUL
0A9A 0DAB+      DC TP,SAXON,SAXON
0A9B 0B49
0A9C 0B49
0A9D 401D+      JMM MOVF
0A9E 0DBD+      DC D0.0,Y1
0A9F 0D4A
0AA0 401D+      JMM MOVF
0AA1 0D48+      DC X1,X2
0AA2 0D5C
0AA3 401D+      JMM MOVF
0AA4 0DBD+      DC D0.0,Y2
0AA5 0D5E
0AA6 4048+      JMM FNEG
0AA7 0D5C+      DC X2
           +ACTION LSTSY
0AA8 C059+      LDX =-4  SAVF INIT POSITION
0AA9 D45A+      LDA Q1+8,1
0AAA 673B+      STA POS1+4,1
0AAB D45B+      LDA Q2+8,1
0AAC 673F+      STA POS2+4,1
0AAD 0201+      INX 1
0AAE 52A9+      JMP *-5
0AAF 401D+      JMM MOVF
0AB0 0B4B+      DC DST2,DIST
0AB1 0B3F
0AB2 D357+      LDA TEST
0AB3 04D1+      SAG 1
0AB4 52C5+      JMP CTH
0AB5 4007+      JMM FMUL  INIT VFL
0AB6 0DDE+      DC KA,X1,U1
0AB7 0D48
0AB8 0D44
0AB9 4007+      JMM FMUL
0ABA 0DDE+      DC KA,Y1,V1
```

```
0ABB  0D4A
0ABC  0D46
0ABD  4007+       JMM FMUL
0ABE  0DE0+       DC KB,Y2,V2
0ABF  0D5E
0AC0  0D5A
0AC1  4007+       JMM FMUL
0AC2  0DE0+       DC KB,X2,U2
0AC3  0D5C
0AC4  0D58
           +CTH   LSTSY
0AC5  4007+       JMM FMUL
0AC6  0B53+       DC ASLOPE,X1,THETA
0AC7  0D48
0AC8  0DAF
0AC9  4045+       JMM FADD
0ACA  0DAF+       DC THETA,AOFF,THETA
0ACB  0B55
0ACC  0DAF
0ACD  404B+       JMM RADIUS
0ACE  0D48+       DC X1,Y1,TP
0ACF  0D4A
0AD0  0DAB
0AD1  4385+       JMM TWIST
0AD2  0D05+       LDI 5
0AD3  602F+       STA PAWS
0AD4  401D+       JMM MOVE
0AD5  0D03+       DC D1,VSH
0AD6  0DD5
0AD7  401D+       JMM MOVE
0AD8  0B3F+       DC DIST,TP
0AD9  0DAB
0ADA  401D+       JMM MOVE
0ADB  0DBD+       DC D0.0,VELD
0ADC  0DE2
0ADD  43DC+       JMM SHIFT
0ADE  401D+       JMM MOVE
0ADF  0B49+       DC SAXON,THETA
0AE0  0DAF
0AF1  401D+       JMM MOVE
0AF2  0B3F+       DC DIST,TP
0AF3  0DAB
0AF4  4385+       JMM TWIST
0AF5  4007+       JMM FMUL
0AF6  0D48+       DC X1,TSLOPE,TP
0AF7  0B4F
0AF8  0DAB
0AF9  4045+       JMM FADD
0AEA  0DAB+       DC TP,TOFF,TP
0AFB  0B51
0AFC  0DAB
0AFD  D35D+       LDA LWHILE
0AFE  602F+       STA PAWS
0AFF  401D+       JMM MOVE
0AF0  0B5F+       DC LVEL,VELD
0AF1  0DE2
0AF2  E358+       INC IFPASS
0AF3  43DC+       JMM SHIFT
0AF4  0D01+       LDI 1
0AF5  4043+       JMM MODE
0AF6  401F+       JMM CRT
0AF7  0BC2+       DC M1.,M2.,4
0AF8  0DEB
0AF9  0004
0AFA  4044+       JMM DECOUT
0AFB  0D48+       DC X1
0AFC  4044+       JMM DECOUT
0AFD  0D4A+       DC Y1
```

```
0AFE 4044+        JMM DECOUT
0AFF 0D5C+        DC X2
0B00 4044+        JMM DECOUT
0B01 0D5E+        DC Y2
0B02 401F+        JMM CRT
0B03 08C2+        DC M1.,M3.,4
0B04 0DED
0B05 0004
0B06 4044+        JMM DECOUT
0B07 0B37+        DC POS1
0B08 4044+        JMM DECOUT
0B09 0B3F+        DC DIST
0B0A 4044+        JMM DECOUT
0B0B 0B49+        DC SAXON
0B0C D357+        LDA TEST
0B0D 601C+        STA FALL
0B0E 505C+        JMP $600
        +*
0B0F 205D+LOCATE STX LOCX
0B10 0700+        LAX 0
0B11 6315+        STA LOX
0B12 0701+        LAX 1
0B13 6316+        STA LOY
0B14 401F+        JMM CRT
0B15 0000+LOX   DC 0
0B16 0000+LOY   DC 00,4
0B17 0004
0B18 4045+        JMM FADD
0B19 16BD+        DC XPOS,D1,XPOS
0B1A 0D03
0B1B 16BD
0B1C 4045+        JMM FADD
0B1D 16BF+        DC YPOS,D1,YPOS
0B1E 0D03
0B1F 16BF
0B20 401F+        JMM CRT
0B21 16BD+        DC XPOS,YPOS,2
0B22 16BF
0B23 0002
0B24 405F+        JMM GIN   MARKER DRAWN.INPUT XHAIRS
0B25 D05F+        LDA YPOS  NO CHANGE IF Y<-1
0B26 04D5+        SAG NUVAL
0B27 D060+        LDA YPOS+1
0B28 04D1+        SAG 1
0B29 0482+        SKP NUVAL
0B2A C05D+        LDX LOCX
0B2B 07C2+        JMX 2
0B2C C05D+NUVAL LDX LOCX  SAVE NEW POS
0B2D D061+        LDA XPOS
0B2E 0340+        SIX 0
0B2F D062+        LDA XPOS+1
0B30 0341+        SIX 1
0B31 0201+        INX 1
0B32 D05F+        LDA YPOS
0B33 0340+        SIX 0
0B34 D060+        LDA YPOS+1
0B35 0341+        SIX 1
0B36 07C1+        JMX 1
        +*
0B37 0000+POS1  DC 0,0,0.0
0B38 0000
0B39 0000
0B3A 0000
0B3B 0000+POS2  DC 0,0,0,0
0B3C 0000
0B3D 0000
0B3E 0000
0B3F 0000+DIST  DC 0,0
```

```
0B40 0000
0B41 8466+OSLOPE DC -.030177B-5,-5
0B42 FFFB
0B43 5E1B+OOFF DC .3676B-1,-1
0B44 FFFF
0B45 C000+M.25 DC -.25B-1,-1
0B46 FFFF
0B47 C000+SAXA DC -.25B-1,-1
0B48 FFFF
0B49 0000+SAXON DC 0.0
0B4A 0000
0B4B 0000+DST2 DC 0,0
0B4C 0000
0B4D 4000+D2.  DC 2.B2,2
0B4E 0002
0B4F DFD3+TSLOPE DC -1.00561B2,2
0B50 0002
0B51 45A9+TOFF DC 8.708B4,4
0B52 0004
0B53 0000+ASLOPE DC 0,0
0B54 0000
0B55 B5C3+AOFF DC -.29B-1,-1
0B56 FFFF
0B57      +TEST DS 1
0B58 0000+IFPASS DC 0
0B59 B000+M10. DC -10.B4.4
0B5A 0004
0B5B 7800+D30. DC 30B5,5
0B5C 0005
0B5D 0000+LWHILE DC 0,0
0B5E 0000
0B5F 0000+LVEL DC 0,0
0B60 0000
0B61 40F4+AP    DC .10149F1B1,1
0B62 0001
0B63 52CB+      DC .66237F3B10.10
0B64 000A
0B65 AD97+      DC -.13186E4B11,11
0B66 000B
0B67 BFBE+      DC -.26321E6B19,19
0B68 0013
0B69 5175+      DC .41708F5B16.16
0B6A 0010
0B6B 4B1F+      DC .30771E6B19.19
0B6C 0013
0B6D 0A6B+BP    DC .10420E2B7,7
0B6E 0007
0B6F 852E+      DC -.78606E4B13,13
0B70 000D
0B71 64B4+      DC .16113F4B11,11
0B72 000B
0B73 B2DC+      DC -.12639E7B21,21
0B74 0015
0B75 7BC4+      DC .20278F7B21,21
0B76 0015
0B77 5179+      DC .16686E6B18,18
0B78 0012
0B79      +XP DS 12
```

```
0B85 2063+TWIST STX TWX
0B86 D01C+       LDA FALL
0B87 04D8+       SAG NW
0B88 0D01+       LDI 1
0B89 4043+       JMM MODE
0B8A 4051+       JMM WIPE
0B8B 4052+       JMM TURER
0B8C 4020+       JMM MSG
0B8D 0DBD+       DC D0.0.M1.03,TURNM
0B8E 0DB7
0B8F 0DC8
         +NW     LSTSY
0B90 401F+       JMM CRT
0B91 0000+       DC 0
0B92 0540+       CLA
0B93 4043+       JMM MODE
0B94 4007+       JMM FMUL
0B95 0DAB+       DC TP,QUANT,TP
0B96 0DB1
0B97 0DAB
0B98 4011+       JMM FSUB
0B99 0D03+       DC D1,TP,TP
0B9A 0DAB
0B9B 0DAB
0B9C 400C+       JMM FDIV
0B9D 0DAF+       DC THETA,TP,THETA
0B9E 0DAB
0B9F 0DAF
0BA0 400C+       JMM FDIV
0BA1 0DAF+       DC THETA,DROTE,TP
0BA2 0CEC
0BA3 0DAB
0BA4 4018+       JMM FIX
0BA5 0DAB+       DC TP
0BA6 D064+       LDA TP
0BA7 0140+       ABA
0BA8 04D1+       SAG 1
0BA9 5863+       JMP *TWX
0BAA 0100+       TWA
0BAB 6064+       STA TP
0BAC 09C8+       SBI 200
0BAD 6065+       STA TP2
0BAE C066+       LDX =-11
0BAF 0540+       CLA
0BB0 6467+       STA OM+11,1
0BB1 0201+       INX 1
0BB2 53B0+       JMP *-2
0BB3 D068+       LDA =$4000  SET OUTER WALL TO 1/SEC
0BB4 6067+       STA OM+11
0BB5 D069+GLP    LDA =-3  COUNT 3 DT'S
0BB6 606A+       STA CT
0BB7 406B+LP      JMM ROTE  UPDATE AIRMOTION
0BB8 406C+       JMM GETOM  CALC ANG VEL AIR AT FIRST DROPLET
0BB9 0D44+       DC Q1
0BBA 406D+       JMM TURNIP  UPDATE DROPLET POSITION
0BBB 0D44+       DC Q1
0BBC 406C+       JMM GETOM   SAME SECOND DROPLET
0BBD 0D58+       DC Q2
0BBE 406D+       JMM TURNIP
0BBF 0D58+       DC Q2
0BC0 406C+       JMM GETOM
0BC1 0D6C+       DC EQ1
0BC2 406D+       JMM TURNIP
0BC3 0D6C+       DC EQ1
0BC4 406C+       JMM GETOM
0BC5 0D82+       DC EQ2
0BC6 406D+       JMM TURNIP
0BC7 0D82+       DC EQ2
```

```
0BC8  E064+        INC  TP
0BC9  0482+        SKP  2
0BCA  0540+        CLA
0BCB  6067+        STA  OM+11
0BCC  E065+        INC  TP2
0BCD  0481+        SKP  1
0BCE  5863+        JMP  *TWX
0BCF  E06A+        INC  CT
0BD0  53B7+        JMP  LP
0BD1  D029+        LDA  TNXT
0BD2  F02A+        CAA  ITIME
0BD3  0482+        SKP  2
0BD4  0481+        SKP  1
0BD5  53D2+        JMP  *-3
0BD6  D02A+        LDA  ITIME
0BD7  6029+        STA  TNXT
0BD8  406E+        JMM  DSPLA
0BD9  401F+        JMM  CRT
0BDA  0001+        DC  1
0BDB  53B5+        JMP  GLP
```

```
0BDC 206F+SHIFT STX SHX
0BDD D01C+      LDA FALL
0BDE 04DA+      SAG NOWIPE
0BDF 0D01+      LDI 1
0BE0 4043+      JMM MODE
0BE1 4051+      JMM WIPE
0BE2 4052+      JMM TUBER
0BE3 D039+      LDA VSH
0BE4 04A4+      SAZ 4
0BE5 4020+      JMM MSG
0BE6 0DBD+      DC D0.0.M1.03,SHFTM
0BE7 0DB7
0BE8 0DCB
0BE9 401F+NOWIPE JMM CRT
0BEA 0000+      DC 0
0BEB 0540+      CLA
0BEC 4043+      JMM MODE
0BED 0540+      CLA
0BEE 6070+      STA VA
0BEF 6071+      STA VA+1
0BF0 D039+      LDA VSH
0BF1 6072+      STA UA
0BF2 D03A+      LDA VSH+1
0BF3 6073+      STA UA+1
0BF4 D064+      LDA TP
0BF5 04D2+      SAG 2
0BF6 4048+      JMM FNEG
0BF7 0FD8+      DC UA
0BF8 400C+      JMM FDIV
0BF9 0DAB+      DC TP,DT,TP
0BFA 0CFF
0BFB 0DAB
0BFC D072+      LDA UA
0BFD 04A4+      SAZ 4  INPTERP TP AS DIST IF VEL NOT ZERO
0BFE 400C+      JMM FDIV
0BFF 0DAB+      DC TP,UA,TP
0C00 0FD8
0C01 0DAB
0C02 4018+      JMM FIX
0C03 0DAB+      DC TP
0C04 D3AB+      LDA TP
0C05 0140+      ABA
0C06 04D1+      SAG 1
0C07 5BC3+      JMP *SHX
0C08 0100+      TWA
0C09 63AB+      STA TP
0C0A 9240+      SUB PAWS
0C0B 63AD+      STA TP2
0C0C D059+DSL   LDA =-4  COUNT 4 DT'S
0C0D 6337+      STA CT
0C0E 406D+SLIDE JMM TURNIP
0C0F 0D44+      DC Q1
0C10 406D+      JMM TURNIP
0C11 0D58+      DC Q2        INTEGRATE EACH DROP ONE STEP
0C12 D03C+      LDA MV1
0C13 04D2+      SAG 2
0C14 406D+      JMM TURNIP
0C15 0D6C+      DC EQ1
0C16 D03D+      LDA MV2
0C17 04D2+      SAG 2
0C18 406D+      JMM TURNIP
0C19 0D82+      DC EQ2
0C1A E040+      INC XTIME
0C1B 0500+      NOP
0C1C 4074+      JMM XHAIR
0C1D D02B+      LDA IFPASS
0C1E 04A7+      SAZ NOPT
0C1F 4011+      JMM FSUB
```

```
0C20  0D48+       DC X1,X2,PTEM
0C21  0D5C
0C22  0C41
0C23  D241+       LDA PTEM
0C24  04D1+       SAG 1
0C25  5BC3+       JMP *SHX
          +NOPT   LSTSY
0C26  F3AB+       INC TP
0C27  0484+        SKP 4
0C28  D3E2+       LDA VELD
0C29  6072+       STA UA
0C2A  D3E3+       LDA VELD+1
0C2B  6073+       STA UA+1
0C2C  E3AD+       INC TP2
0C2D  0481+       SKP 1
0C2E  5BC3+       JMP *SHX
0C2F  E337+       INC CT   AND DISPLAY EVERY 4 TIMES
0C30  520E+       JMP SLIDE
0C31  D3D3+       LDA TNXT
0C32  F3D4+       CAA ITIME
0C33  0482+       SKP 2
0C34  0481+       SKP 1
0C35  5232+       JMP *-3
0C36  D3D4+       LDA ITIME
0C37  63D3+       STA TNXT
0C38  4255+       JMM DSPLA
0C39  D072+       LDA UA
0C3A  04A1+       SAZ 1
0C3B  0481+       SKP 1
0C3C  405E+       JMM GIN
0C3D  401F+       JMM CRT
0C3E  0001+       DC 1
0C3F  520C+       JMP DSL
0C40  0000+PAWS   DC 0
0C41  0000+PTEM   DC 0,0
0C42  0000
```

```
0C43 0D9B+WIPE  LDI $9B   CLEAR SCREEN (MODE 1 ASSUMED)
0C44 224A+       STX WPX
0C45 4058+       JMM PAK
0C46 0D8C+       LDI $8C
0C47 4058+       JMM PAK
0C48 424B+       JMM WAITP
0C49 5A4A+       JMP *WPX
          +*
0C4A 0000+WPX   DC 0
0C4B D069+WAITP LDA =-3
0C4C 6254+       STA WINC
0C4D 0540+       CLA
0C4E 0901+       SRI 1
0C4F 04A1+       SAZ 1
0C50 524E+       JMP *-2
0C51 E254+       INC WINC
0C52 524D+       JMP WAITP+2
0C53 07C0+       JMX 0
0C54 0000+WINC  DC 0
          +*
0C55 2299+DSPLA STX DSX
0C56 401F+       JMM CRT
0C57 0000+       DC 0
0C58 4045+       JMM FADD
0C59 0D4A+       DC Y1,D.1,WS
0C5A 08C4
0C5B 0D01
0C5C 4011+       JMM FSUB
0C5D 0D48+       DC X1,D.1,WS2
0C5E 08C4
0C5F 0FD6
0C60 401F+       JMM CRT
0C61 0D48+       DC X1,Y1,4
0C62 0D4A
0C63 0004
0C64 401F+       JMM CRT
0C65 0FD6+       DC WS2,WS,2
0C66 0D01
0C67 0002
0C68 4011+       JMM FSUB
0C69 0D70+       DC EX1,D.1,WS
0C6A 08C4
0C6B 0D01
0C6C 4011+       JMM FSUB
0C6D 0D72+       DC EY1,D.1,WS2
0C6E 08C4
0C6F 0FD6
0C70 401F+       JMM CRT
0C71 0D70+       DC EX1,EY1,4
0C72 0D72
0C73 0004
0C74 401F+       JMM CRT
0C75 0D01+       DC WS,WS2,2
0C76 0FD6
0C77 0002
0C78 4045+       JMM FADD
0C79 0D5E+       DC Y2,D.1,WS
0C7A 08C4
0C7B 0D01
0C7C 4011+       JMM FSUB
0C7D 0D5C+       DC X2,D.1,WS2
0C7E 08C4
0C7F 0FD6
0C80 401F+       JMM CRT
0C81 0D5C+       DC X2,Y2,4
0C82 0D5E
0C83 0004
0C84 401F+       JMM CRT
```

```
0C85 0FD6+       DC WS2,WS,2
0C86 0D01
0C87 0002
0C88 4011+       JMM FSUB
0C89 0D86+       DC EX2,D.1,WS
0C8A 08C4
0C8B 0D01
0C8C 4011+       JMM FSUB
0C8D 0D88+       DC EY2,D.1,WS2
0C8E 08C4
0C8F 0FD6
0C90 401F+       JMM CRT
0C91 0D86+       DC EX2,EY2,4
0C92 0D88
0C93 0004
0C94 401F+       JMM CRT
0C95 0D01+       DC WS,WS2,2
0C96 0FD6
0C97 0002
0C98 5A99+       JMP *DSX
0C99      +DSX   DS 1
```

```
0C9A 2343+ROTE  STX RX   UPDATE ATR ANGULAR VFL
0C9B 0D01+      LDI 1
0C9C 6338+      STA IM1
0C9D C075+      LDX =-10  (10 INTERIOR POINTS)
0C9E D076+SLP   LDA =.5B1
0C9F 632B+      STA E
0CA0 0540+      CLA
0CA1 04F0+      DIV
0CA2 0000+      DC 0,E,IM1
0CA3 0D2B
0CA4 0D38
0CA5 632B+      STA E    E=.5/(I-1)=DR/2R
0CA6 8068+      ADD =1B1
0CA7 632D+      STA G  G=1+E
0CA8 D068+      LDA =1B1
0CA9 932B+      SUB E
0CAA 632F+      STA H  H=1-E
0CAB D2DD+      LDA BR   B AT B-1   OR 4B AT B1
0CAC 04F0+      MPY
0CAD 0000+      DC 0,E,P   P=4BE (AT B2)
0CAE 0D2B
0CAF 0D31
0CB0 D331+      LDA P
0CB1 0C01+      LLN 1  NOW AT B1
0CB2 0100+      TWA
0CB3 82DE+      ADD CR
0CB4 D2DE+      LDA CR
0CB5 6331+      STA P   P=C-4BE   AT B1
0CB6 D711+      LDA OM+12,1
0CB7 04E0+      MPY
0CB8 0000+      DC 0,G,G   G=GOM(I+1)
0CB9 0D2D
0CBA 0D2D
0CBB 632D+      STA G        AT B2
0CBC D710+      LDA OM+11,1
0CBD 04F0+      MPY
0CBE 0000+      DC 0,P,P
0CBF 0D31
0CC0 0D31
0CC1 6331+      STA P    P=POM(I)  AT B2
0CC2 D70F+      LDA OM+10,1
0CC3 04E0+      MPY
0CC4 0000+      DC 0,H,H
0CC5 0D2F
0CC6 0D2F
0CC7 632F+      STA H    H=HOM(I-1)  AT B2
0CC8 832D+      ADD G
0CC9 04E0+      MPY
0CCA 0000+      DC 0,BR,G
0CCB 0CDD
0CCC 0D2D
0CCD 632D+      STA G   G=(B AT B-1)(G+H AT B2)  =AT B1
0CCE D331+      LDA P   AT B2
0CCF 0C01+      LLN 1
0CD0 832D+      ADD G
0CD1 671C+      STA OMP+11,1
0CD2 E338+      INC IM1
0CD3 0201+      INX 1
0CD4 529E+      JMP SLP
0CD5 D312+      LDA OMP+1   SET OMP(1)=OMP(2)
0CD6 6311+      STA OMP
0CD7 C066+       LDX =-11
0CD8 D71C+       LDA OMP+11,1
0CD9 6710+       STA OM+11,1
0CDA 0201+      INX 1
0CDB 52D8+      JMP *-3
0CDC 5B43+      JMP *RX
0CDD 0000+BR    DC 0
```

```
0CDE 0000+CR     DC 0
         +*
0CDF 0000+CALCOMP DC 0
0CE0 0001+ONE    DC 1
0CE1 0004+FOUR DC 4
0CE2 6AC2+COEF DC $6AC2,-10  9ETA/2
0CE3 FFF6
0CE4 6666+OMEGA DC 1.6B1.1
0CE5 0001
0CE6 B9C8+SHIFTY DC -$4638,-6  -3/350  THREE INCREMENTS
0CE7 FFFA
0CE8 0000+ANG   DC 0,0
0CE9 0000
0CEA 6488+PI    DC $6488,2
0CEB 0002
0CEC 0000+DROTE DC 0,0
0CED 0000
0CEE 0000+QMOD DC 0
0CEF 0000+XOFF DC 0,0
0CF0 0000
0CF1 0000+YOFF DC 0,0
0CF2 0000
0CF3 6C22+R0    DC .0033B-8,-8
0CF4 FFF8
0CF5 0000+C3    DC 0,0
0CF6 0000
0CF7 0000+C4    DC 0,0
0CF8 0000
0CF9 4DD3+NU    DC $4DD3,-2
0CFA FFFE
0CFB 5D17+I11   DC $5D17,-3  1/11
0CFC FFFD
0CFD 0000+DR    DC 0,0
0CFE 0000
0CFF 0000+DT    DC 0,0
0D00 0000
0D01 0000+WS    DC 0,0
0D02 0000
0D03 4000+D1    DC $4000,1
0D04 0001
0D05      +OM   DS 12
0D11      +OMP  DS 12
0D1D      +F    DS 6
0D23 0000+A     DC 0,0
0D24 0000
0D25 0000+B     DC 0,0
0D26 0000
0D27 0000+C     DC 0,0
0D28 0000
0D29 0000+D   DC 0,0
0D2A 0000
0D2B 0000+E     DC 0,0
0D2C 0000
0D2D 0000+G     DC 0,0
0D2E 0000
0D2F 0000+H     DC 0,0
0D30 0000
0D31 0000+P     DC 0,0
0D32 0000
0D33 0000+Q     DC 0,0
0D34 0000
0D35 4000+P5    DC $4000,0
0D36 0000
0D37 0000+CT    DC 0
0D38 0000+IM1   DC 0,0
0D39 0000
0D3A 0000+LX    DC 0
0D3B 0000+TEMP DC 0
```

```
0D3C 0000+PTR    DC 0
0D3D 0000+EKS    DC 0,0
0D3E 0000
0D3F 0000+WYE    DC 0,0
0D40 0000
0D41 6666+P1     DC $6666,-3   .1
0D42 FFFD
0D43 0000+RX     DC 0
         +Q1     LSTSY
0D44 0000+U1     DC 0,0
0D45 0000
0D46 0000+V1     DC 0,0
0D47 0000
0D48 0000+X1     DC 0,0
0D49 0000
0D4A 0000+Y1     DC 0,0
0D4B 0000
0D4C 0000+C11    DC 0,0
0D4D 0000
0D4E 0000+UX1    DC 0,0
0D4F 0000
0D50 0000+VX1    DC 0,0
0D51 0000
0D52 0000+XX1    DC 0,0
0D53 0000
0D54 0000+YX1    DC 0,0
0D55 0000
0D56 6F69+R1     DC .0068B-7,-7
0D57 FFF9
         +Q2     LSTSY
0D58 0000+U2     DC 0,0
0D59 0000
0D5A 0000+V2     DC 0,0
0D5B 0000
0D5C 0000+X2     DC 0,0
0D5D 0000
0D5E 0000+Y2     DC 0,0
0D5F 0000
0D60 0000+C21    DC 0,0
0D61 0000
0D62 0000+UX2    DC 0,0
0D63 0000
0D64 0000+VX2    DC 0,0
0D65 0000
0D66 0000+XX2    DC 0,0
0D67 0000
0D68 0000+YX2    DC 0,0
0D69 0000
0D6A 6C22+R2     DC .0066B-7,-7
0D6B FFF9
         +EQ1    LSTSY
0D6C 0000+EU1    DC 0,0
0D6D 0000
0D6E 0000+EV1    DC 0,0
0D6F 0000
0D70 0000+EX1    DC 0,0
0D71 0000
0D72 0000+EY1    DC 0,0
0D73 0000
0D74 0000+EC11 DC 0,0
0D75 0000
0D76 0000+EUX1   DC 0,0
0D77 0000
0D78 0000+EVX1   DC 0,0
0D79 0000
0D7A 0000+EXX1   DC 0,0
0D7B 0000
0D7C 0000+EYX1   DC 0,0
```

```
0D7D  0000
0D7E  0000+ER1   DC 0,0
0D7F  0000
0D80  0000+LOC01 DC 0,0
0D81  0000
           +EQ2   LSTSY
0D82  0000+EU2   DC 0,0
0D83  0000
0D84  0000+EV2   DC 0,0
0D85  0000
0D86  0000+EX2   DC 0,0
0D87  0000
0D88  0000+EY2   DC 0,0
0D89  0000
0D8A  0000+EC21  DC 0,0
0D8B  0000
0D8C  0000+EUX2   DC 0,0
0D8D  0000
0D8E  0000+EVX2   DC 0,0
0D8F  0000
0D90  0000+EXX2   DC 0,0
0D91  0000
0D92  0000+EYX2   DC 0,0
0D93  0000
0D94  0000+ER2   DC 0,0
0D95  0000
0D96  0000+LOC02 DC 0,0
0D97  0000
0D98       +ESTF1 DS 1
0D99  0000+ESTF2 DC 0
0D9A  D2C1+REST  TXT,16 RADIUS TRUE/EST
0D9B  C4C9
0D9C  D5D3
0D9D  A0D4
0D9E  D2D5
0D9F  C5AF
0DA0  C5D3
0DA1  D4A0
0DA2  0000+      DC 0
0DA3  8CCD+M.9   DC -.9B0,0
0DA4  0000
0DA5  8334+M.975 DC -.975B0,0
0DA6  0000
0DA7  5A1C+RTURB DC 5.5E-3B-7,-7
0DA8  FFF9
0DA9  5800+D11   DC $5800,4
0DAA  0004
0DAB  0000+TP    DC 0,0
0DAC  0000
0DAD  0000+TP2   DC 0,0
0DAE  0000
0DAF  0000+THETA DC 0,0
0DB0  0000
0DB1  7AED+QUANT DC $7AED,-4
0DB2  FFFC
0DB3  A261+M1.46 DC -$5D9F,1
0DB4  0001
0DB5  5D9F+D1.46 DC $5D9F,1
0DB6  0001
0DB7  BE2C+M1.03 DC -$41D4,1
0DB8  0001
0DB9  41D4+D1.03 DC $41D4,1
0DBA  0001
0DBB  A261+M.006 DC $-5D9F,-7
0DBC  FFF9
0DBD  0000+D0.0 DC 0,0
0DBE  0000
0DBF  5D9F+D.006 DC $5D9F,-7
```

```
0DC0 FFF9
0DC1 0000+WHICH DC 0
0DC2 0000+TWX   DC 0
0DC3 0000+SHX   DC 0
0DC4 0000+PKX   DC 0
0DC5 0000+PX    DC 0,0
0DC6 0000
0DC7 0000+PRX   DC 0
0DC8 D4D5+TURNM TXT,4 TURN
0DC9 D2CE
0DCA 0000+      DC 0
0DCB D3C8+SHFTM TXT,6 SHIFT
0DCC C9C6
0DCD D4A0
0DCE 0000+      DC 0
0DCF 0000+TUBX  DC 0
0DD0 AB00+PLUS  DC $AB00,0
0DD1 0000
0DD2 001B+TS    DC 27
0DD3 0000+TNXT  DC 0
0DD4 0000+ITIME DC 0
0DD5 0000+VSH   DC 0,0
0DD6 0000
0DD7 9C00+M400. DC -400B9,9
0DD8 0009
0DD9 0000+TINC DC 0,0
0DDA 0000
0DDB 5000+D10. DC 10B4,4
0DDC 0004
0DDD 0000+CL2   DC 0
0DDE 0000+KA    DC 0,0
0DDF 0000
0DE0 0000+KB    DC 0,0
0DE1 0000
0DE2 0000+VELD DC 0,0
0DE3 0000
0DE4 0000+SCALE DC 0,0
0DE5 0000
0DE6 0000+FALL DC 0
0DE7 0000+OMS2 DC 0,0
0DE8 0000
0DE9 72B0+R02   DC .0035B-8,-8
0DEA FFF8
0DEB C000+M2.   DC -2.B2,2
0DEC 0002
0DED A000+M3.   DC -3.B2,2
0DEE 0002
0DEF 0000+LOCX DC 0
0DF0 5780+D350. DC 350B9,9
0DF1 0009
0DF2 7000+D14. DC 14B4,4
0DF3 0004
0DF4 4000+SMALL DC .5B0,-20
0DF5 FFEC
0DF6 4000+D.5   DC .5B0,0
0DF7 0000
0DF8 4333+D1.05 DC 1.05B1,1
0DF9 0001
0DFA 5000+D5. DC 5.B3,3
0DFB 0003
0DFC 6666+D.4   DC .4B-1,-1
0DFD FFFF
0DFE 999A+M.4   DC -.4B-1,-1
0DFF FFFF
0E00 8000+M.5   DC $8000,-1
0E01 FFFF
0E02 B100+Z1    DC $B100,0
0E03 0000
```

```
0E04 B200+72    DC $B200,0
0E05 0000
0E06       +XTIME DS 1
```

```
0E07 2077+PICKX STX PKX
0E08 4078+       JMM NORMAL
0E09 0DC5+       DC PX
0E0A 400C+       JMM FDIV
0E0B 0DC5+       DC PX,D9.,PX
0E0C 0E14
0E0D 0DC5
0E0E C077+       LDX PKX
0E0F D079+       LDA PX
0E10 0340+       SIX 0
0E11 D07A+       LDA PX+1
0E12 0341+       SIX 1
0E13 07C1+       JMX 1
0E14 4800+D9.  DC 9.B4,4
0E15 0004
          +*
0E16 207B+PICKR STX PRX
0E17 4078+       JMM NORMAL
0E18 0DC5+       DC PX
0E19 400C+       JMM FDIV
0E1A 0DC5+       DC PX,D32.,PX
0E1B 0E2B
0E1C 0DC5
0E1D 4045+       JMM FADD
0E1E 0D03+       DC D1,PX,PX
0E1F 0DC5
0E20 0DC5
0E21 4007+       JMM FMUL
0E22 0DC5+       DC PX,R0,PX
0E23 0CF3
0E24 0DC5
0E25 C07B+       LDX PRX
0E26 D079+       LDA PX
0E27 0340+       SIX 0
0E28 D07A+       LDA PX+1
0E29 0341+       SIX 1
0E2A 07C1+       JMX 1
0E2B 4000+D32. DC 32B6,6
0E2C 0006
          +*
0E2D 22D0+XHAIR STX XHX
0E2E D2D1+       LDA XRED   NEW XHAIR INPUT?
0E2F 04A1+       SAZ 1
0E30 07C0+       JMX 0   NO
0E31 D2D4+       LDA FITTING  DROP LOCKED TO XHAIR?
0E32 04D1+       SAG 1
0E33 523D+       JMP IFMK
0E34 407C+       JMM FIXGIN
0E35 4045+       JMM FADD  CALC DESIRED POSITION
0E36 17F0+       DC XLOC,XSCREP
0E37 0ED8
0E38 0000+XH3    DC 000
0E39 4045+       JMM FADD
0E3A 17F2+       DC YLOC,YSCREP
0E3B 0EDA
0E3C 0000+XH4    DC 000
0E3D D02D+IFMK  LDA MARK   ISOPOSITION MARKED?
0E3E 04D3+       SAG XMK
0E3F 0D01+XXIT  LDI 1  NO,SET TO ACCEPT NEW POSITION
0E40 62D1+       STA XRED
0E41 5AD0+       JMP *XHX
0E42 62D6+XMK   STA NUTIME  SAVE TIME
0E43 62ED+       STA NUTIME2
0E44 0540+       CLA
0E45 602D+       STA MARK    AND CLEAR
0E46 D2D4+       LDA FITTING  DROP BEING MOVED
0E47 04A1+       SAZ 1
0E48 5270+       JMP XHCALC  YES,MOVING DONE
```

```
0E49 0D01+        LDI 1
0E4A 62D4+        STA FITTING  START UP OF DROP RFLOCATION
0E4B 407C+        JMM FIXGIN
0E4C D07D+        LDA XLOC  SIGN OF X DTERMINES WHICH DROP IS MEANT
0E4D 62D5+        STA X1OR2
0E4E 04B2+        SAN 2
0E4F D07E+        LDA =EX2
0E50 04B1+        SKP 1
0E51 D07F+        LDA =EX1
0E52 625A+        STA XH1  POINT TO PROPER X
0E53 6238+        STA XH3
0E54 6271+        STA XH5
0E55 0802+        ADI 2
0E56 625E+        STA XH2
0E57 623C+        STA XH4  TO PROPER Y
0E58 6272+        STA XH6
0E59 4011+        JMM FSUB  CALC OFFSET OF XHAIR FROM DROP
0E5A 0000+XH1     DC 000,XLOC,XSCREP
0E5B 17F0
0E5C 0ED8
0E5D 4011+        JMM FSUB
0E5E 0000+XH2     DC 000,YLOC,YSCREP
0E5F 17F2
0E60 0EDA
0E61 D2D5+        LDA X1OR2  FETCH LAST MARKED TIME AND RADIUS
0E62 04B6+        SAN L1
0E63 E2E8+        INC MV2  NOTE DROP 2 BEING HANDLED
0E64 401D+        JMM MOVE
0E65 0EEA+        DC R2OLD,ROLD
0E66 0EDC
0E67 D2EC+        LDA T2OLD
0E68 04B5+        SKP L2
0E69 E2E3+L1      INC MV1
0E6A 401D+        JMM MOVE
0E6B 0EE5+        DC R1OLD,ROLD
0E6C 0EDC
0E6D D2E7+        LDA T1OLD
0E6E 62DE+L2      STA OLDTIME
0E6F 523F+        JMP XXIT
0E70 404B+XHCALC JMM RADIUS  CALC RADIAL POS
0E71 0000+XH5     DC 000
0E72 0000+XH6     DC 000,RNU
0E73 0EDF
0E74 D2D5+        LDA X1OR2  IS THIS THE FIRST TIME FOR THIS DROP
0E75 04B1+        SAN 1
0E76 527C+        JMP L3
0E77 D2E4+        LDA DID1
0E78 04A1+        SAZ 1
0E79 5281+        JMP XDOIT
0E7A E2E4+        INC DID1  1ST FOR #1
0E7B 52C4+        JMP FIX1
0E7C D2E9+L3      LDA DID2
0E7D 04A1+        SAZ 1
0E7E 5281+        JMP XDOIT
0E7F E2E9+        INC DID2  1ST FOR #2
0E80 52B9+        JMP FIX2
0E81 400C+XDOIT JMM FDIV  CALC TIME CONST DELTA
0E82 0EDF+        DC RNU,ROLD,A
0E83 0EDC
0E84 0D23
0E85 4080+        JMM LOG2
0E86 0D23+        DC A,A
0E87 0D23
0E88 4007+        JMM FMUL
0E89 0D23+        DC A,LOGE2,A
0E8A 0EE1
0E8B 0D23
0E8C D2D6+        LDA NUTIME
```

```
0E8D 92DE+       SUB OLDTIME
0E8E 62D6+       STA NUTIME
0E8F 4081+       JMM FLOAT
0E90 0ED6+       DC NUTIME
0E91 4007+       JMM FMUL
0E92 0ED6+       DC NUTIME,DT,NUTIME
0E93 0CFF
0E94 0ED6
0E95 400C+       JMM FDIV
0E96 0D23+       DC A,NUTIME,XHDELT
0E97 0ED6
0E98 0EEE
0E99 4007+       JMM FMUL  CALC DROP RADIUS
0E9A 0EEE+       DC XHDELT,XHDELT,A
0E9B 0EEE
0E9C 0D23
0E9D 400C+       JMM FDIV
0E9E 0D23+       DC A,OMS2,A
0E9F 0DE7
0EA0 0D23
0EA1 4007+       JMM FMUL
0EA2 0D23+       DC A,D5.,A
0EA3 0DFA
0EA4 0D23
0EA5 4045+       JMM FADD
0EA6 0D23+       DC A,D1,A
0EA7 0D03
0EA8 0D23
0EA9 4007+       JMM FMUL
0EAA 0D23+       DC A,XHDELT,A
0EAB 0EEE
0EAC 0D23
0EAD 4007+       JMM FMUL
0EAE 0D23+       DC A,XHCOF,A
0EAF 0ED2
0EB0 0D23
0EB1 4050+       JMM SQRT
0EB2 0D23+       DC A,A
0EB3 0D23
0EB4 D2D5+       LDA X1OR2
0EB5 04BB+       SAN SET1
0EB6 401D+       JMM MOVE
0EB7 0D23+       DC A,ER2
0EB8 0D94
0EB9 433D+FIX2   JMM XCOFF
0EBA 0D82+       DC EQ2
0EBB 401D+       JMM MOVE
0EBC 0EDF+       DC RNU,R2OLD
0EBD 0EEA
0EBE D2ED+       LDA NUTIME2
0EBF 62EC+       STA T2OLD
0EC0 52CB+       JMP XSHUT
0EC1 401D+SET1   JMM MOVE
0EC2 0D23+       DC A,ER1
0EC3 0D7E
0EC4 433D+FIX1   JMM XCOFF
0EC5 0D6C+       DC EQ1
0EC6 401D+       JMM MOVE
0EC7 0EDF+       DC RNU,R1OLD
0EC8 0EE5
0EC9 D2ED+       LDA NUTIME2
0ECA 62E7+       STA T1OLD
0ECB 0540+XSHUT  CLA
0ECC 62D4+       STA FITTING
0ECD 62E3+       STA MV1
0ECE 62E8+       STA MV2
0ECF 523F+       JMP XXIT
          +*
```

```
0ED0       +XHX   DS  1
0ED1       +XRED DS 1
0ED2       +XHCOF DS 2
0ED4       +FITTING DS 1
0ED5       +X1OR2 DS 1
0ED6       +NUTIME DS 2
0ED8       +XSCREP DS 2
0EDA       +YSCREP DS 2
0EDC       +ROLD DS 2
0EDE       +OLDTIME DS 1
0EDF       +RNU  DS 2
0EE1  58B9+LOGE2 DC .69317280,0
0EE2  0000
0EE3  0000+MV1   DC 0
0EE4  0000+DID1  DC 0
0EE5  0000+R1OLD DC 0,0
0EE6  0000
0EE7  0000+T1OLD DC 0
0EE8  0000+MV2   DC 0
0EE9  0000+DID2  DC 0
0EEA  0000+R2OLD DC 0,0
0EEB  0000
0EEC  0000+T2OLD DC 0
0EED  0000+NUTIME2 DC 0
0EEE  0000+XHDELT DC 0,0
0EEF  0000
           +*
0EF0  2327+EXP2  STX XPX   Y=2.**X
0EF1  0300+      LIX 0
0EF2  6328+      STA TEX
0EF3  0301+      LIX 1
0EF4  6329+      STA TEX+1
0EF5  0700+      LAX 0
0EF6  62FF+      STA AEX
0EF7  4018+      JMM FIX
0EF8  0F28+      DC TEX
0EF9  D328+      LDA TEX
0EFA  0801+      ADI 1
0EFB  632B+      STA AEXP+1
0EFC  4081+      JMM FLOAT
0EFD  0F28+      DC TEX
0EFE  4011+      JMM FSUB
0EFF  0000+AEX   DC 000,TEX,TEX
0F00  0F28
0F01  0F28
0F02  4012+      JMM FRACT
0F03  0F28+      DC TEX
0F04  D328+      LDA TEX
0F05  04E0+      MPY
0F06  0000+      DC 0,CX4,TEX+1
0F07  0F30
0F08  0F29
0F09  0CC3+      ARS 3
0F0A  832F+      ADD CX3
0F0B  04E0+      MPY
0F0C  0000+      DC 0,TEX,TEX+1
0F0D  0F28
0F0E  0F29
0F0F  0CC2+      ARS 2
0F10  832E+      ADD CX2A
0F11  04E0+      MPY
0F12  0000+      DC 0,TEX,TEX+1
0F13  0F28
0F14  0F29
0F15  0CC1+      ARS 1
0F16  832D+      ADD CX1A
0F17  04E0+      MPY
0F18  0000+      DC 0,TEX,TEX+1
```

```
0F19 0F28
0F1A 0F29
0F1B 0CC1+        ARS 1
0F1C 832C+        ADD CX0
0F1D 632A+        STA AEXP
0F1E 4082+        JMM NORM
0F1F 0F2A+        DC AEXP
0F20 C327+        LDX XPX
0F21 0201+        INX 1
0F22 D32A+        LDA AEXP
0F23 0340+        SIX 0
0F24 D32B+        LDA AEXP+1
0F25 0341+        SIX 1
0F26 07C1+        JMX 1
0F27 0000+XPX     DC 0
0F28 0000+TEX     DC 0,0
0F29 0000
0F2A 0000+AEXP DC 0,0
0F2B 0000
0F2C 4000+CX0     DC .500002443280
0F2D 58AB+CX1A    DC .3463618917B-1
0F2E 3D79+CX2A    DC .1200693491B-2
0F2F 3A90+CX3     DC .2859587553E-1B-4
0F30 50B4+CX4     DC .4925754022F-2B-7
          +*
0F31 0000+EXX DC 0
0F32 0000+ESX     DC 0
0F33 0000+EA      DC 0,0
0F34 0000
0F35 0000+EB      DC 0,0
0F36 0000
0F37 0000+EC      DC 0,0
0F38 0000
0F39 4000+D.25 DC .25B-1,-1
0F3A FFFF
0F3B 6000+D.75 DC .75B0.0
0F3C 0000
          +*
0F3D 238D+XCOEF STX XCX
0F3E 0700+        LAX 0
0F3F 0814+        ADI 20
0F40 6083+        STA PTRA
0F41 C084+        LDX =-20
0F42 DC83+        LDA *PTRA,1
0F43 644D+        STA PT+20,1
0F44 0201+        INX 1
0F45 5342+        JMP *-3
0F46 400C+        JMM FDIV
0F47 0CE2+        DC COEF,RT,CK
0F48 1080
0F49 0F94
0F4A 400C+        JMM FDIV
0F4B 0F94+        DC CK,RT,CK
0F4C 1080
0F4D 0F94
0F4E 4007+        JMM FMUL
0F4F 0F94+        DC CK,DT,CT1
0F50 0CFF
0F51 1076
0F52 400C+        JMM FDIV
0F53 0DE7+        DC OMS2.CK,CDELT
0F54 0F94
0F55 0F8E
0F56 4007+        JMM FMUL
0F57 0F8E+        DC CDELT,OMEGA,CEPS
0F58 0CE4
0F59 0F90
0F5A 400C+        JMM FDIV
```

```
0F5B 0F90+        DC CEPS,CK,CEPS
0F5C 0F94
0F5D 0F90
0F5E 4007+        JMM FMUL
0F5F 0F90+        DC CEPS,M2.,CEPS
0F60 0DFB
0F61 0F90
0F62 4007+        JMM FMUL
0F63 1072+        DC XT,CDELT,UT
0F64 0F8E
0F65 106E
0F66 4007+        JMM FMUL
0F67 1074+        DC YT,CDELT,VT
0F68 0F8E
0F69 1070
0F6A 4007+        JMM FMUL
0F6B 1074+        DC YT,CEPS,XCT
0F6C 0F90
0F6D 0F92
0F6E 4011+        JMM FSUB
0F6F 106E+        DC UT,XCT,UT
0F70 0F92
0F71 106E
0F72 4007+        JMM FMUL
0F73 1072+        DC XT,CEPS,XCT
0F74 0F90
0F75 0F92
0F76 4045+        JMM FADD
0F77 1070+        DC VT,XCT,VT
0F78 0F92
0F79 1070
0F7A 4085+        JMM DFIX
0F7B 106E+        DC UT,UXT
0F7C 1078
0F7D 4085+        JMM DFIX
0F7E 1070+        DC VT,VXT
0F7F 107A
0F80 4085+        JMM DFIX
0F81 1072+        DC XT,XXT
0F82 107C
0F83 4085+        JMM DFIX
0F84 1074+        DC YT,YXT
0F85 107E
0F86 C084+        LDX =-20
0F87 D44D+        LDA PT+20,1
0F88 6C83+        STA *PTRA,1
0F89 0201+        INX 1
0F8A 5387+        JMP *-3
0F8B C38D+        LDX XCX
0F8C 07C1+        JMX 1
          +*
0F8D      +XCX   DS 1
0F8E      +CDELT DS 2
0F90      +CEPS  DS 2
0F92      +XCT   DS 2
0F94      +CK    DS 2
```

```
0F96 23D0+GETOM STX GX   CALC AIR ANG VEL AT GIVEN POINT
0F97 CBD0+       LDX *GX   GET ADDRESS OF ARG LIST
0F98 0208+       INX 8  POINT AFTER X AND Y
0F99 23D1+       STX GPTR
0F9A C059+       LDX =-4
0F9B DFD1+       LDA *GPTR,1
0F9C 67D6+       STA GP+4,1
0F9D 0201+       INX 1
0F9E 539B+       JMP *-3
0F9F 404B+       JMM RADIUS
0FA0 0FD2+       DC XG,YG,WS
0FA1 0FD4
0FA2 0D01
0FA3 4007+       JMM FMUL   CALC INDEX INTO OM ARRAY
0FA4 0D01+       DC WS,D11,WS
0FA5 0DA9
0FA6 0D01
0FA7 D008+       LDA WS   SAVE VALUE
0FA8 63D6+       STA WS2  FOR INTERPOLATION
0FA9 D00A+       LDA WS+1
0FAA 63D7+       STA WS2+1
0FAB 4018+       JMM FIX
0FAC 0D01+       DC WS
0FAD 4012+       JMM FRACT
0FAE 0FD6+       DC WS2
0FAF D3D6+       LDA WS2  CLEAR ONE"S BIT OF NUMBER SCALED B0
0FB0 B086+       ANA =$7FFF
0FB1 63D6+       STA WS2
0FB2 C008+       LDX WS   INDEX INTO ANG VEL ARRAY AND DO INTERPL
0FB3 D487+       LDA OM+1,1
0FB4 9488+       SUB OM,1
0FB5 04E0+       MPY
0FB6 0000+       DC 0,WS2,WS  TIMES FRACTION BETWEEN VALUES
0FB7 0FD6
0FB8 0D01
0FB9 8488+       ADD OM,1
0FBA 6008+       STA WS
0FBB D04A+       LDA THETA  WHICH DIRECTION ARE WE GOING?
0FBC 04D3+       SAG 3
0FBD D008+       LDA WS  CHANGE SIGN FOR NEG ANGLE
0FBE 0100+       TWA
0FBF 6008+       STA WS
0FC0 0D01+       LDI 1  INDICATE BINARY POINT
0FC1 600A+       STA WS+1
0FC2 4082+       JMM NORM  AND FLOAT
0FC3 0D01+       DC WS
0FC4 4007+        JMM FMUL  CALC AIR VELOCITY
0FC5 0D01+        DC WS,XG,VA
0FC6 0FD2
0FC7 0FDA
0FC8 4007+        JMM FMUL
0FC9 0D01+        DC WS,YG,UA
0FCA 0FD4
0FCB 0FD8
0FCC 4048+        JMM FNEG
0FCD 0FD8+        DC UA
0FCE C3D0+        LDX GX
0FCF 07C1+        JMX 1
          +*
0FD0 0000+GX     DC 0
0FD1 0000+GPTR DC 0
          +GP     LSTSY
0FD2 0000+XG     DC 0,0
0FD3 0000
0FD4 0000+YG     DC 0,0
0FD5 0000
0FD6 0000+WS2   DC 0,0
0FD7 0000
```

```
0FD8 0000+UA    DC 0,0
0FD9 0000
0FDA 0000+VA    DC 0,0
0FDB 0000
```

```
0FDC 2089+TURNIP STX TX  INTEGRATE DROPLET ONE STEP
0FDD 0700+       LAX 0
0FDE 0814+       ADI 20
0FDF 6083+       STA PTRA
0FE0 C084+       LDX =-20
0FE1 DC83+       LDA *PTRA,1
0FE2 644D+       STA PT+20,1
0FE3 0201+       INX 1   MOVE ARGS TO WORK AREA
0FE4 53E1+       JMP *-3
0FE5 4007+       JMM FMUL
0FE6 1076+       DC CT1,UT,E1  E1=KDT*U
0FE7 106E
0FE8 1064
0FE9 4007+       JMM FMUL
0FEA 0CF5+       DC C3,VT,D2  D2=2OMDTV
0FEB 1070
0FEC 1066
0FED 4007+       JMM FMUL
0FEE 0CF7+       DC C4,XT,D3  D3=OM**2DTX
0FEF 1072
0FF0 1068
0FF1 4007+       JMM FMUL
0FF2 1076+       DC CT1,UA,WS  WS=KDTUA
0FF3 0FD8
0FF4 0D01
0FF5 408A+       JMM DADD
0FF6 1078+       DC UXT,WS,UP
0FF7 0D01
0FF8 106A
0FF9 4048+       JMM FNEG
0FFA 1064+       DC E1
0FFB 408A+       JMM DADD
0FFC 106A+       DC UP,E1,UP
0FFD 1064
0FFE 106A
0FFF 408A+       JMM DADD
1000 106A+       DC UP,D2,UP
1001 1066
1002 106A
1003 408A+       JMM DADD
1004 106A+       DC UP,D3,UP
1005 1068
1006 106A
1007 4007+       JMM FMUL
1008 0CF5+       DC C3,UT,E1  E1=OMDTU
1009 106E
100A 1064
100B 4007+       JMM FMUL
100C 1076+       DC CT1,VT,D2  D2=KDTV
100D 1070
100E 1066
100F 4007+       JMM FMUL
1010 0CF7+       DC C4,YT,D3  D3=OM**2DTY
1011 1074
1012 1068
1013 4007+       JMM FMUL
1014 1076+       DC CT1,VA,WS
1015 0FDA
1016 0D01
1017 408A+       JMM DADD
1018 107A+       DC VXT,WS,VP
1019 0D01
101A 106C
101B 4048+       JMM FNEG
101C 1064+       DC E1
101D 4048+       JMM FNEG
101E 1066+       DC D2
101F 408A+       JMM DADD
```

```
1020 106C+      DC VP,E1.VP
1021 1064
1022 106C
1023 408A+      JMM DADD
1024 106C+      DC VP,D2,VP
1025 1066
1026 106C
1027 408A+      JMM DADD
1028 106C+      DC VP,D3,VP
1029 1068
102A 106C
102B 408B+      JMM DAVER
102C 1078+      DC UXT,UP,WS
102D 106A
102E 0D01
102F 408C+      JMM DFLOAT
1030 0D01+      DC WS,WS
1031 0D01
1032 4007+      JMM FMUL
1033 0D01+      DC WS,DT,WS
1034 0CFF
1035 0D01
1036 408A+      JMM DADD
1037 107C+      DC XXT,WS,XXT
1038 0D01
1039 107C
103A 408C+      JMM DFLOAT
103B 107C+      DC XXT,XT
103C 1072
103D 408B+      JMM DAVER
103E 107A+      DC VXT,VP,WS
103F 106C
1040 0D01
1041 408C+      JMM DFLOAT
1042 0D01+      DC WS,WS
1043 0D01
1044 4007+      JMM FMUL
1045 0D01+      DC WS,DT.WS
1046 0CFF
1047 0D01
1048 408A+      JMM DADD
1049 107E+      DC YXT,WS,YXT
104A 0D01
104B 107E
104C 408C+      JMM DFLOAT
104D 107E+      DC YXT,YT
104E 1074
104F 401D+      JMM MOVE
1050 106A+      DC UP,UXT
1051 1078
1052 408C+      JMM DFLOAT
1053 1078+      DC UXT,UT
1054 106E
1055 401D+      JMM MOVE
1056 106C+      DC VP,VXT
1057 107A
1058 408C+      JMM DFLOAT
1059 107A+      DC VXT,VT
105A 1070
105B C084+      LDX =-20  REPLACE UPDATED ARGS
105C D682+      LDA PT+20,1
105D 6E63+      STA *PTRA,1
105E 0201+      INX 1
105F 525C+      JMP *-3
1060 C262+      LDX TX
1061 07C1+      JMX 1
          +*
1062 0000+TX    DC 0
```

```
1063 0000+PTRA  DC 0
1064 0000+E1    DC 0,0
1065 0000
1066 0000+D2    DC 0,0
1067 0000
1068 0000+D3    DC 0,0
1069 0000
106A 0000+UP    DC 0,0
106B 0000
106C 0000+VP    DC 0,0
106D 0000
         +PT    LSTSY
106E 0000+UT    DC 0,0
106F 0000
1070 0000+VT    DC 0,0
1071 0000
1072 0000+XT    DC 0,0
1073 0000
1074 0000+YT    DC 0,0
1075 0000
1076 0000+CT1   DC 0,0
1077 0000
1078 0000+UXT   DC 0,0
1079 0000
107A 0000+VXT   DC 0,0
107B 0000
107C 0000+XXT   DC 0,0
107D 0000
107E 0000+YXT   DC 0,0
107F 0000
1080 0000+RT    DC 0,0
1081 0000
```

```
1082 0300+HALF  LIX 0
1083 04A2+      SAZ 2
1084 0301+      LIX 1
1085 0901+      SBI 1
1086 0341+      SIX 1
1087 07C1+      JMX 1
         +*
1088 0300+TWICE LIX 0
1089 04A2+      SAZ 2
108A 0301+      LIX 1
108B 0801+      ADI 1
108C 0341+      SIX 1
108D 07C1+      JMX 1
         +*
108E 22F0+ATAN  STX ATX
108F 0300+      LIX 0
1090 62F3+      STA Y
1091 0504+      SEX S
1092 04B1+      SAN 1
1093 05C4+      REX S
1094 0301+      LIX 1
1095 62F4+      STA Y+1
1096 0433+      SNS 3
1097 4048+      JMM FNEG
1098 10F3+      DC Y
1099 C2F0+      LDX ATX
109A 0201+      INX 1
109B 0301+      LIX 1
109C 62F2+      STA X+1
109D 0300+      LIX 0
109E 62F1+      STA X
109F 04B3+      SAN 3
10A0 05C8+      REX R
10A1 0540+      CLA
10A2 0484+      SKP 4
10A3 4048+      JMM FNEG
10A4 10F1+      DC X
10A5 0508+      SEX R
10A6 D068+      LDA =$4000
10A7 8076+      ADD =$2000
10A8 62F5+      STA QUAD
10A9 D2F4+      LDA Y+1
10AA F2F2+      CAA X+1
10AB 0481+      SKP 1
10AC D2F2+      LDA X+1
10AD 0180+      ONA
10AE 62F6+      STA EXP
10AF 82F4+      ADD Y+1
10B0 62F4+      STA Y+1
10B1 D2F2+      LDA X+1
10B2 82F6+      ADD EXP
10B3 62F2+      STA X+1
10B4 4012+      JMM FRACT
10B5 10F1+      DC X
10B6 4012+      JMM FRACT
10B7 10F3+      DC Y
10B8 D2F1+      LDA X
10B9 82F3+      ADD Y
10BA 0801+      ADI 1
10BB 62F7+      STA T
10BC D2F3+      LDA Y
10BD 92F1+      SUB X
10BE 04F0+      DIV
10BF 0000+      DC 0,T,T
10C0 10F7
10C1 10F7
10C2 62F1+      STA X
10C3 04E0+      MPY
```

```
10C4 0000+       DC 0,X,T
10C5 10F1
10C6 10F7
10C7 62F3+       STA Y
10C8 04E0+       MPY
10C9 0000+       DC 0,K7,T
10CA 10FB
10CB 10F7
10CC 0CC2+       ARS 2
10CD 82FA+       ADD K5
10CE 04E0+       MPY
10CF 0000+       DC 0,Y,T
10D0 10F3
10D1 10F7
10D2 0CC1+       ARS 1
10D3 82F9+       ADD K3
10D4 04E0+       MPY
10D5 0000+       DC 0,Y,T
10D6 10F3
10D7 10F7
10D8 0CC2+       ARS 2
10D9 82F8+       ADD K1
10DA 04E0+       MPY
10DB 0000+       DC 0,X,T
10DC 10F1
10DD 10F7
10DE 0CC1+       ARS 1
10DF 0421+       SNR 1
10E0 0100+       TWA
10E1 82F5+       ADD QUAD
10E2 0431+       SNS 1
10E3 0100+       TWA
10E4 62F3+       STA Y
10E5 0540+       CLA
10E6 62F4+       STA Y+1
10E7 4082+       JMM NORM
10E8 10F3+       DC Y
10E9 C2F0+       LDX ATX
10EA 0202+       INX 2
10EB D2F3+       LDA Y
10EC 0340+       SIX 0
10ED D2F4+       LDA Y+1
10EE 0341+       SIX 1
10EF 07C1+       JMX 1
10F0 0000+ATX  DC 0
10F1 0000+X      DC 0,0
10F2 0000
10F3 0000+Y      DC 0,0
10F4 0000
10F5 0000+QUAD DC 0
10F6 0000+EXP  DC 0
10F7 0000+T    DC 0
10F8 516B+K1   DC $516B (-1)
10F9 978B+K3   DC -$6875 (-3)
10FA 5E73+K5   DC $5E73 (-4)
10FB 9C56+K7 DC   -$63AA (-6)
```

```
10FC 2321+NORMAL STX NX
10FD D08D+       LDA =-12
10FE 6322+       STA NCT
10FF 0540+       CLA
1100 631F+       STA NSUM
1101 4315+       JMM RANDM
1102 0C83+       LRN 3
1103 831F+       ADD NSUM
1104 631F+       STA NSUM
1105 E322+       INC NCT
1106 5301+       JMP *-5
1107 D31F+       LDA NSUM
1108 0C81+       LRN 1
1109 908E+       SUB =$3000 6.B4
110A 631F+       STA NSUM
110B 0D04+       LDI 4
110C 6320+       STA NSUM+1
110D 4082+       JMM NORM
110E 111F+       DC NSUM
110F C321+       LDX NX
1110 D31F+       LDA NSUM
1111 0340+       SIX 0
1112 D320+       LDA NSUM+1
1113 0341+       SIX 1
1114 07C1+       JMX 1
          +*
1115 2323+RANDM STX RNX
1116 D31E+       LDA VAL
1117 0801+       ADI 1
1118 04E0+       MPY
1119 0000+       DC 0,VAL,VAL
111A 111F
111B 111E
111C D31E+       LDA VAL
111D 07C0+       JMX 0
          +*
111E 0001+VAL    DC 1
111F 0000+NSUM   DC 0,0
1120 0000
1121 0000+NX     DC 0
1122 0000+NCT    DC 0
1123 0000+RNX    DC 0
          +*
1124 2344+RADIUS STX RAX     SQRT(X*X+Y+Y)
1125 0300+       LIX 0
1126 6345+       STA XR
1127 0301+       LIX 1
1128 6346+       STA XR+1
1129 0201+       INX 1
112A 0300+       LIX 0
112B 6347+       STA YR
112C 0301+       LIX 1
112D 6348+       STA YR+1
112E 4007+       JMM FMUL
112F 1145+       DC XR,XR,XR
1130 1145
1131 1145
1132 4007+       JMM FMUL
1133 1147+       DC YR,YR,YR
1134 1147
1135 1147
1136 4045+       JMM FADD
1137 1145+       DC XR,YR,XR
1138 1147
1139 1145
113A 4349+       JMM SQRT
113B 1145+       DC XR,YR
113C 1147
```

```
113D C344+       LDX RAX
113E 0202+       INX 2
113F D347+       LDA YR
1140 0340+       SIX 0
1141 D348+       LDA YR+1
1142 0341+       SIX 1
1143 07C1+       JMX 1
         +*
1144 0000+RAX     DC 0
1145 0000+XR     DC 0,0
1146 0000
1147 0000+YR     DC 0,0
1148 0000
         +*
1149 237A+SQRT  STX SQX
114A 0301+       LIX 1   GET EXP
114B 0CC1+       ARS 1 /2  LOW BIT TO C
114C 6382+       STA SQEXP
114D 0300+       LIX 0 GET MANT
114E 04D4+       SAG 4
114F 0540+       CLA  IF <=0  RETURN ZERO
1150 6381+       STA SQT
1151 6382+       STA SQEXP
1152 5373+       JMP SQXIT
1153 0C81+       LRN 1  SCALE BY 1
1154 6383+       STA RAND
1155 0404+       SNC 4
1156 E382+       INC SQEXP  ADJUST VALUE FOR ODD EXP
1157 0500+       NOP
1158 0504+       SEX S
1159 0482+       SKP 2
115A 05C4+       REX S
115B 0300+       LIX 0  USE UNSCALED VALUE IF EXP EVEN
115C 0C8C+       LRN 12  GET UPPER 3 BITS
115D 0600+       XXA
115E D779+       LDA TRIAL-2,1  GET APPROX ANSWER FROM TABLE
115F 6381+       STA SQT
1160 6384+       STA RAND+1
1161 D08F+       LDA =-2  SET UP TO DO TWO ITERATIONS
1162 6385+       STA SQCT
1163 D383+SQLP  LDA RAND  A/X
1164 04F0+       DIV
1165 0000+       DC 0,RAND+1,SQT
1166 1184
1167 1181
1168 0431+       SNS 1
1169 0C81+       LRN 1
116A 6386+       STA SQTP
116B D381+       LDA SQT
116C 0C81+       LRN 1
116D 8386+       ADD SQTP  (X+A/X)/2
116E 04D1+       SAG 1  REDUCE IF >1
116F D086+       LDA =$7FFF
1170 6381+       STA SQT
1171 E385+       INC SQCT
1172 5363+       JMP SQLP
1173 C37A+SQXIT LDX SQX
1174 0201+       INX 1
1175 D381+       LDA SQT
1176 0340+       SIX 0
1177 D382+       LDA SQEXP
1178 0341+       SIX 1
1179 07C1+       JMX 1
         +*
117A 0000+SQX   DC 0
117B 478E+TRIAL DC $478F,$54AA,$6000,$6A22,$7361,$7BEF
117C 54AA
117D 6000
```

```
117E 6A22
117F 7361
1180 7BEF
1181 0000+SQT   DC 0
1182 0000+SQEXP DC 0
1183 0000+RAND  DC 0,0
1184 0000
1185 0000+SQCT  DC 0
1186 0000+SQTP  DC 0
```

```
1187 23F8+DECOUT STX DCX
1188 0300+       LIX 0
1189 63F9+       STA DA  GET VALUE
118A 0301+       LIX 1
118B 63FA+       STA DA+1
118C D3F9+       LDA DA
118D 05C2+       REX B  REMOVE SIGN
118E 04D3+       SAG 3
118F 4048+       JMM FNEG
1190 11F9+       DC DA
1191 0502+       SEX B
1192 0540+       CLA   CALC DECIMAL EXPONENT
1193 63FB+       STA DEXP
1194 C090+RESCALE LDX =0  SEARCH FOR NEAREST POWER OF TEN
1195 0D08+       LDI 8
1196 63FC+       STA DELX
1197 D3FA+SEEK  LDA DA+1  COMPARE WITH POWER OF TEN
1198 F491+       CAA TENTAB+1.1
1199 53A2+       JMP XUP  TRY BIGGER POWER
119A 53AB+       JMP XDOWN TRY LOWER
119B D3F9+       LDA DA
119C F492+       CAA TENTAB.1
119D 53A2+       JMP XUP
119E 53AB+       JMP XDOWN
119F 0201+OSH   INX 1  OVERSHOOT TO NEXT POWER
11A0 53B2+       JMP DSC
11A1 53B2+       JMP DSC
11A2 0600+XUP   XXA
11A3 83FC+       ADD DELX  X GOES UP
11A4 0600+       XXA
11A5 D3FC+       LDA DELX
11A6 04C1+       SLZ 1
11A7 53B2+       JMP DSC
11A8 0C81+SDELX LRN 1
11A9 63FC+       STA DELX
11AA 5397+       JMP SEEK
11AB 0600+XDOWN XXA  X GOES DOWN
11AC 93FC+       SUB DELX
11AD 0600+       XXA
11AE D3FC+       LDA DELX
11AF 04C1+       SLZ 1
11B0 53B2+       JMP DSC
11B1 53A8+       JMP SDELX
11B2 D491+DSC   LDA TENTAB+1.1  SCAL BY POWER
11B3 63FD+       STA DSCALE
11B4 D493+       LDA TENTAB+2.1
11B5 63FF+       STA DSCALE+1
11B6 0600+       XXA    SAVE AMOUNT OF SCALE
11B7 0801+       ADI 1
11B8 0CC1+       ARS 1
11B9 63FC+       STA DELX
11BA 83FB+       ADD DEXP
11BB 63FB+       STA DEXP
11BC 400C+       JMM FDIV
11BD 11F9+       DC DA,DSCALE.DA
11BE 11FD
11BF 11F9
11C0 D3FC+       LDA DELX  WAS NUMBER WITHIN RANGE OF TABLE^
11C1 0908+       SBI 8
11C2 04B1+       SAN 1
11C3 5394+       JMP RESCALE  NO,BIGGER
11C4 080F+       ADI 15
11C5 04D1+       SAG 1
11C6 5394+       JMP RESCALE  NO,SMALLER
11C7 4012+       JMM FRACT
11C8 11F9+        DC DA  CONVERT TO FIXED FRACTION
11C9 C094+       LDX =-5  EXTRACT 5 DIGITS
11CA 0D0A+DEXT  LDI 10
```

```
11CB 04E0+        MPY
11CC 0000+        DC 0,DA,DA
11CD 11F9
11CE 11F9
11CF 08B0+        ADI $B0  CONVERT TO ASCI
11D0 6495+        STA DIGZ+8,1
11D1 0201+        INX 1
11D2 53CA+        JMP DEXT
11D3 D096+        LDA DIGZ+3  MOVE DIGIT TO INSERT .
11D4 6097+        STA DIGZ+2
11D5 0DAE+        LDI $AE
11D6 6096+        STA DIGZ+3
11D7 0DA0+        LDI $A0  CHOOSE BLNK OR - FOR SIGN
11D8 0441+        SNB 1
11D9 0DAD+        LDI $AD
11DA 6098+        STA DIGZ+1
11DB 0DA0+        LDI $A0
11DC 63FF+        STA DIGZ
11DD D3FB+        LDA DEXP  GET EXPONENT
11DE 0901+        SBI 1  REMOVE OVERSHOOT
11DF 63FB+        STA DEXP
11E0 04B2+        SAN 2
11E1 0DAB+        LDI $AB
11E2 0481+        SKP 1
11E3 0DAD+        LDI $AD
11E4 6095+        STA DIGZ+8  SAVE EXPONENT SIGN
11E5 D3FB+        LDA DEXP
11E6 0140+        ABA
11E7 63FB+        STA DEXP
11E8 0540+        CLA
11E9 04F0+        DIV
11EA 000A+        DC 10,DEXP,*-2
11EB 11FB
11EC 11EA
11ED 08B0+        ADI $B0  CONVERT TO ASCI
11EE 6099+        STA DIGZ+9
11EF D3FB+        LDA DEXP
11F0 08B0+        ADI $B0
11F1 609A+        STA DIGZ+10
11F2 4020+        JMM MSG   PUT OUT RESULT
11F3 16BD+        DC XPOS,YPOS,DIGZ
11F4 16BF
11F5 11FF
11F6 C3F8+        LDX DCX
11F7 07C1+        JMX 1
11F8 0000+DCX  DC 0
11F9 0000+DA      DC 0,0
11FA 0000
11FB 0000+DEXP  DC 0
11FC 0000+DELX  DC 0
11FD 0000+DSCALE DC 0,0
11FE 0000
11FF      +DIGZ  DS 11
120A 0000+        DC 0
          +*  START OF TENTAB
120B 6B5F+        DC 1E-7B-23,-23,1E-6B-19,-19,1E-5B-16,-16,1E-4B-13,-13
120C FFE9
120D 431B
120E FFED
120F 53E2
1210 FFF0
1211 68DB
1212 FFF3
1213 4189+        DC .001B-9,-9,.01B-6,-6,.1B-3,-3
1214 FFF7
1215 51EB
1216 FFFA
1217 6666
```

```
1218 FFFD
1219 4000+TENTAB DC 1B1,1
121A 0001
121B 5000+       DC 10B4,4,100B7,7,1000B10,10
121C 0004
121D 6400
121E 0007
121F 7D00
1220 000A
1221 4E20+       DC 1E4B14,14,1E5B17,17,1E6B20,20,1E7B24,24
1222 000E
1223 61A8
1224 0011
1225 7A12
1226 0014
1227 4C4B
1228 0018
1229 5F5E+       DC 1E8B27,27
122A 001B
```

```
122B 225D+MSG   STX MSX
122C 0700+      LAX 0
122D 6235+      STA MARG1
122E 623B+      STA MARG3
122F 0701+      LAX 1
1230 6236+      STA MARG2
1231 623C+      STA MARG4
1232 0702+      LAX 2
1233 623D+      STA MPTR
1234 401F+      JMM CRT  MOVE BEAM TO INDICATED POSITION
1235 0000+MARG1 DC 0
1236 0000+MARG2 DC 0,4
1237 0004
1238 D016+      LDA CALCOMP  IF CALCOMP IN USE PUT OUT CHARS THERE
1239 04A4+      SAZ 4
123A 409B+      JMM SYMBOL
123B 0000+MARG3 DC 0
123C 0000+MARG4 DC 0
123D 0000+MPTR DC 0
123E 401F+      JMM CRT
123F 0002+      DC 2
1240 0D9F+      LDI $9F
1241 4282+      JMM PAK
1242 0540+      CLA
1243 625E+      STA WCNT
1244 DA3D+MOUT  LDA *MPTR  GET NEXT OUTPUT WORD
1245 04AB+      SAZ ZIT  ZERO IS END OF MESSAGE
1246 0C88+      LRN 8
1247 04A2+      SAZ 2
1248 4282+      JMM PAK
1249 E25E+      INC WCNT
124A DA3D+      LDA *MPTR
124B B09C+      ANA =$FF
124C 04A2+      SAZ 2
124D 4282+      JMM PAK
124E E25E+      INC WCNT
124F E23D+      INC MPTR
1250 5244+      JMP MOUT
1251 4081+ZIT   JMM FLOAT
1252 125E+      DC WCNT  UPDATE POSITION BY WIDTH OF MSG
1253 4007+      JMM FMUL
1254 125E+      DC WCNT,WIDTH,WCNT
1255 1260
1256 125E
1257 4045+      JMM FADD
1258 16BD+      DC XPOS,WCNT,XPOS
1259 125E
125A 16BD
125B C25D+      LDX MSX
125C 07C3+      JMX 3
          +*
125D 0000+MSX   DC 0
125E 0000+WCNT  DC 0,0
125F 0000
1260 5214+WIDTH DC .0400782B-4,-4
1261 FFFC
          +*
1262 0B46+EDO   EDO 4,6
1263 5262+      JMP *-1
1264 07C0+      JMX 0
          +* SHUT OFF DISPLAY
          +* 1=ENTER STORAGE MODE (DATA NOT BUFFERED)
          +* 0=ENTER WRITE THRU MODE (REPETATIVE)
          +*-1=ENTER WRITE THRU MODE (NON-REPET)
1265 227C+MODE  STX MOX
1266 627D+      STA QMODO
1267 D09D+      LDA =SKWASH
1268 609E+      STA $18  KILL CRT INTERRUPT
```

```
1269  D09F+        LDA =10000  WAIT FOR POISON TO ACT
126A  0901+        SBI 1
126B  04A1+        SAZ 1
126C  526A+        JMP *-2
126D  0A47+        EDI 4,7  EAT ANY CHARACTER LAYING ARROUND
126E  0500+        NOP
126F  D27D+        LDA QMODO  PUT SCOPE IN MODE
1270  04D1+        SAG 1
1271  5277+        JMP FANTOM
1272  0D9B+        LDI $9B  ENTER STORAGE MODE
1273  4262+        JMM EDO
1274  0DE0+        LDI $E0
1275  4262+        JMM EDO
1276  5A7C+        JMP *MOX
1277  0D9B+FANTOM LDI $9B
1278  4262+        JMM EDO
1279  0DF0+        LDI $F0
127A  4262+        JMM EDO
127B  5A7C+        JMP *MOX
127C  0000+MOX    DC 0
127D  0000+QMODO DC 0
          +*
127E  0540+SKWASH CLA
127F  0B46+        EDO 4,6
1280  127F+        JRL *-1
1281  127F+        JRL *-2
          +*
1282  62A1+PAK    STA PKA
1283  D27D+        LDA QMODO  IF STORAGE MODE OUTPUT DIRECTLY
1284  04D1+        SAG 1
1285  0484+        SKP 4
1286  D2A1+        LDA PKA
1287  0B46+        EDO 4,6
1288  5287+        JMP *-1
1289  07C0+        JMX 0
128A  D2A1+        LDA PKA
128B  B09C+        ANA =$FF
128C  04D2+        SAG 2
128D  D2A1+        LDA PKA
128E  07C0+        JMX 0
128F  62A3+        STA PKT
1290  22A2+        STX PAX
1291  D2A4+        LDA PKP
1292  0CC1+        ARS 1
1293  0600+        XXA
1294  0404+        SNC 4
1295  0700+        LAX 0
1296  A2A3+        ORA PKT
1297  0740+        SAX 0
1298  0485+        SKP 5
1299  D2A3+        LDA PKT
129A  0C08+        LLN 8
129B  0740+        SAX 0
129C  0540+        CLA
129D  0741+        SAX 1
129E  E2A4+        INC PKP
129F  D2A1+        LDA PKA
12A0  5AA2+        JMP *PAX
          +*
12A1  0000+PKA    DC 0
12A2  0000+PAX    DC 0
12A3  0000+PKT    DC 0
12A4  0000+PKP    DC 0
          +*
12A5  E01A+KLOK   INC TINC+1
12A6  12A5+        JRL KLOK
12A7  D019+        LDA TINC
12A8  601A+        STA TINC+1
```

```
12A9 E02A+       INC ITIME
12AA 12A5+       JRL KLOK
12AB 12A5+       JRL KLOK
           **
12AC 231D+FSCENQ STX GIX
12AD 0D9B+       LDI $9B
12AE 4282+       JMM PAK   READ IN POSITION OF BEAM
12AF 0D85+       LDI $85
12B0 4282+       JMM PAK
12B1 52D2+       JMP GCOORD
12B2 231D+GIN    STX GIX   READ IN POSITION OF CROSSHAIRS
12B3 D2A4+       LDA PKP
12B4 04C2+       SLZ 2
12B5 0D96+       LDI $96
12B6 4282+       JMM PAK
12B7 D2A4+       LDA PKP
12B8 90A0+       SUB PKP1
12B9 90A0+       SUB PKP1
12BA 60A1+       STA BLEN2
12BB 0D9B+       LDI $9B
12BC 4282+       JMM PAK
12BD 0D9A+       LDI $9A
12BE 4282+       JMM PAK
12BF D27D+       LDA QMODO
12C0 04D1+       SAG 1
12C1 0482+       SKP 2
12C2 C094+       LDX =-5
12C3 52D4+       JMP GCOORD+2
12C4 D053+       LDA =-14
12C5 6327+       STA GCNT
12C6 0D96+       LDI $96
12C7 4282+       JMM PAK
12C8 E327+       INC GCNT
12C9 52C7+       JMP *-2
12CA 0D9B+       LDI $9B
12CB 4282+       JMM PAK
12CC 0D85+       LDI $85
12CD 4282+       JMM PAK
12CE 0D01+       LDI 1
12CF 631E+       STA GINI
12D0 5B1D+       JMP *GIX
12D1 231D+RDCORD STX GIX
12D2 0501+GCOORD SEX H
12D3 C059+       LDX =-4
12D4 0A47+IGIN   EDI 4,7
12D5 52D4+       JMP *-1
12D6 6727+       STA GL+5,1
12D7 0201+       INX 1
12D8 52D4+       JMP IGIN
12D9 05C1+       REX H
12DA C0A2+       LDX =-115  SEE IF CR COMES THRU
12DB 0A47+H2     EDI 4,7
12DC 048D+       SKP H1
12DD 098D+       SBI $8D
12DE 04A1+       SAZ 1
12DF 52EC+       JMP H3
12E0 D321+       LDA GINSW
12E1 04A1+       SAZ 1
12E2 52EE+       JMP H4  IGNORE MULTIPLE READS OF XHAIR
12E3 D040+       LDA XTIME
12E4 602D+       STA MARK  MARK TIME OF CR
12E5 0D87+       LDI $87
12E6 0B46+       EDO 4,6
12E7 52E6+       JMP *-1
12E8 E321+       INC GINSW
12E9 52EE+       JMP H4
12EA 0201+H1     INX 1
12EB 52DB+       JMP H2
```

```
12FC 0540+H3     CLA
12FD 6321+       STA GINSW
12FE D323+H4     LDA GL+1   CONVERT TO COORDS
12FF B0A3+       ANA =$1F
12F0 0C05+       LLN 5
12F1 6061+       STA XPOS
12F2 D324+       LDA GL+2
12F3 B0A3+       ANA =$1F
12F4 A061+       ORA XPOS
12F5 90A4+       SUB =512
12F6 6061+       STA XPOS
12F7 D325+       LDA GL+3
12F8 B0A3+       ANA =$1F
12F9 0C05+       LLN 5
12FA 605F+       STA YPOS
12FB D326+       LDA GL+4
12FC B0A3+       ANA =$1F
12FD A05F+       ORA YPOS
12FE 90A5+       SUB =390
12FF 605F+       STA YPOS
1300 0540+       CLA
1301 6041+       STA XRED
1302 0460+       TLA
1303 04A1+       SAZ 1
1304 5319+       JMP GEX
1305 4081+       JMM FLOAT
1306 16BD+       DC XPOS
1307 4081+       JMM FLOAT
1308 16BF+       DC YPOS
1309 400C+       JMM FDIV
130A 16BD+       DC XPOS,SCALF,XPOS
130B 0DE4
130C 16BD
130D 400C+       JMM FDIV
130E 16BF+       DC YPOS,SCALF,YPOS
130F 0DE4
1310 16BF
1311 4045+       JMM FADD
1312 16BD+       DC XPOS,XOFF,XPOS
1313 0CFF
1314 16BD
1315 4045+       JMM FADD
1316 16BF+       DC YPOS,YOFF,YPOS
1317 0CF1
1318 16BF
1319 0540+GEX    CLA
131A 631E+       STA GINI
131B D322+       LDA GL
131C 5B1D+       JMP *GIX
131D 0000+GIX    DC 0
131E 0000+GINI   DC 0
131F 5780+D350   DC 350B9,9
1320 0009
1321      +GINSW DS 1
1322      +GL    DS 5
1327      +GCNT  DS 1
          +*
1328 233E+FIXGIN STX FGX
1329 4081+       JMM FLOAT
132A 17F0+       DC XLOC
132B 4081+       JMM FLOAT
132C 17F2+       DC YLOC
132D 400C+       JMM FDIV
132E 17F0+       DC XLOC,SCALF,XLOC
132F 0DE4
1330 17F0
1331 400C+       JMM FDIV
1332 17F2+       DC YLOC,SCALE,YLOC
```

```
1333 0DE4
1334 17F2
1335 4045+        JMM FADD
1336 17F0+        DC XLOC,XOFF,XLOC
1337 0CEF
1338 17F0
1339 4045+        JMM FADD
133A 17F2+        DC YLOC,YOFF,YLOC
133B 0CF1
133C 17F2
133D 5B3E+        JMP *FGX
133E      +FGX    DS 1
```

```
133F 2373+LOG2 STX ALX   BASE 2 LOGARITMS
1340 0300+     LIX 0  CALC MANTISSA
1341 90A6+     SUB =.75B0
1342 0C02+     LLN 2
1343 6374+     STA LARG
1344 04F0+     MPY
1345 0000+     DC 0,G5,LT
1346 137A
1347 1375
1348 0CC2+     ARS 2
1349 837B+     ADD G4
134A 04F0+     MPY
134B 0000+     DC 0,LARG,LT
134C 1374
134D 1375
134E 0CC2+     ARS 2
134F 837C+     ADD G3
1350 04E0+     MPY
1351 0000+     DC 0,LARG,LT
1352 1374
1353 1375
1354 0CC2+     ARS 2
1355 837D+     ADD G2
1356 04E0+     MPY
1357 0000+     DC 0,LARG,LT
1358 1374
1359 1375
135A 0CC3+     ARS 3
135B 837E+     ADD G1
135C 04E0+     MPY
135D 0000+     DC 0,LARG,LT
135E 1374
135F 1375
1360 837F+     ADD G0
1361 6375+     STA LT   SAVE MANTISSA
1362 0301+     LIX 1  GET CHARACTERISTIC
1363 6377+     STA LZ
1364 4081+     JMM FLOAT
1365 1377+     DC LZ
1366 0540+     CLA   ADD TOGETHER
1367 6376+     STA LT+1
1368 4045+     JMM FADD
1369 1375+     DC LT,LZ,LZ
136A 1377
136B 1377
136C C373+     LDX ALX
136D 0201+     INX 1
136E D377+     LDA LZ
136F 0340+     SIX 0
1370 D378+     LDA LZ+1
1371 0341+     SIX 1
1372 07C1+     JMX 1
          +*
1373 0000+ALX  DC 0
1374 0000+LARG DC 0
1375 0000+LT   DC 0,0
1376 0000
1377 0000+LZ   DC 0,0
1378 0000
1379 0CC0+LARSO ARS 000
137A 59F7+G5   DC  .1372774016E-2B-9
137B AE12+G4   DC -.5000696106E-2B-7
137C 488F+G3   DC  .1771476639E-1B-5
137D AE25+G2   DC -.7993726338E-1B-3
137E 3D8E+G1   DC  .4809106146B0
137F CAE0+G0   DC -.4150495026B0
```

```
1380  0501+MIZL  SEX H
1381  0D04+      LDI 4
1382  0F46+      ECO 4,6   TURN ON INT
1383  5382+      JMP *-1
1384  C001+      LDX =$74
1385  D002+      LDA =KLOK
1386  0740+      SAX 0
1387  0540+      CLA
1388  0743+      SAX 3
1389  05C1+      REX H
138A  401D+      JMM MOVF
138B  14D4+      DC D72.2,SCALF
138C  0DF4
138D  401D+      JMM MOVF
138E  14D6+      DC D7.09,XOFF
138F  0CEF
1390  401D+      JMM MOVF
1391  14D8+      DC D5.4,YOFF
1392  0CF1
1393  401D+      JMM MOVF
1394  0D03+      DC D1,W
1395  14DE
1396  401E+SETUP JMM ZERO
1397  0D44+      DC U1,V1,G
1398  0D46
1399  0D2D
139A  0000+      DC 0
139B  401D+      JMM MOVF
139C  0DF6+      DC D.5,X1
139D  0D48
139E  401D+      JMM MOVF
139F  0DF6+      DC D.5,Y1
13A0  0D4A
13A1  401D+      JMM MOVF
13A2  0F39+      DC D.25,D
13A3  0D29
13A4  4050+      JMM SQRT
13A5  0DF6+      DC D.5,FU1
13A6  0D6C
13A7  4007+      JMM FMUL
13A8  0D6C+      DC EU1,W,FU1
13A9  14DE
13AA  0D6C
13AB  401D+      JMM MOVF
13AC  0D6C+      DC EU1,FV1
13AD  0D6E
13AE  0D01+      LDI 1
13AF  4265+      JMM MODE
13B0  42B2+      JMM GIN
13B1  4011+      JMM FSUB
13B2  16BD+      DC XPOS,X1,EX1
13B3  0D48
13B4  0D70
13B5  4011+      JMM FSUB
13B6  16BF+      DC YPOS,Y2,EY2
13B7  0D5E
13B8  0D88
13B9  D04E+      LDA =-1
13BA  4265+      JMM MODE
13BB  401F+      JMM CRT
13BC  0000+      DC 0
13BD  42B2+      JMM GIN
13BE  401F+      JMM CRT
13BF  0001+      DC 1
13C0  50A7+      JMP WGIN
                +*
13C1  4328+RECALC JMM FIXGIN  COMPLETE COORD CONV
13C2  401D+      JMM MOVF
```

```
13C3 17F0+        DC XLOC,X2
13C4 0D5C
13C5 401D+        JMM MOVF
13C6 17F2+        DC YLOC,Y2
13C7 0D5E
13C8 422B+        JMM MSG
13C9 0D48+        DC X1,Y1,D0.0
13CA 0D4A
13CB 0DBD
13CC 422B+        JMM MSG
13CD 0D5C+        DC X2,Y2,D0.0
13CE 0D5E
13CF 0DBD
13D0 42B2+        JMM GIN
13D1 D2A4+        LDA PKP
13D2 90A0+        SUB PKP1
13D3 90A0+        SUB PKP1
13D4 0804+        ADI 4
13D5 60A8+        STA Q
13D6 401F+        JMM CRT START DISPL
13D7 0001+        DC 1
13D8 4081+        JMM FLOAT CALC DISP TIME
13D9 0D33+        DC Q
13DA 400C+        JMM FDIV
13DB 0D33+        DC Q,D960.,Q
13DC 14DC
13DD 0D33
13DE 4011+        JMM FSUB
13DF 0D5C+        DC X2,X1,A  GET RF POS
13E0 0D48
13E1 0D23
13E2 4011+        JMM FSUB
13E3 0D5E+        DC Y2,Y1,B
13E4 0D4A
13E5 0D25
13E6 4011+        JMM FSUB  ESTIMATE VELOCITY
13E7 0D23+        DC A,EX1,WS
13E8 0D70
13E9 0D01
13EA 400C+        JMM FDIV
13EB 0D01+        DC WS,Q,G  RELATIVE X VEL
13EC 0D33
13ED 0D2D
13EE 4011+        JMM FSUB
13EF 0D25+        DC B,EY1,WS
13F0 0D72
13F1 0D01
13F2 400C+        JMM FDIV
13F3 0D01+        DC WS,Q,H
13F4 0D33
13F5 0D2F
13F6 D069+        LDA =-3
13F7 60A9+        STA TEMP
          +NEWT   LSTSY
13F8 40AA+        JMM LIE
13F9 0D6C+        DC EU1,A,C
13FA 0D23
13FB 0D27
13FC 40AA+        JMM LIF
13FD 0D23+        DC A,G,E
13FE 0D2D
13FF 0D2B
1400 43D5+        JMM DOT
1401 0D6C+        DC EU1,A,P
1402 0D23
1403 0D31
1404 43D5+        JMM DOT
1405 0D6C+        DC EU1,G,R
```

```
1406 0D2D
1407 14E0
1408 4007+        JMM FMUL
1409 0D31+        DC P,C,WS
140A 0D27
140B 0D01
140C 4015+        JMM TWICE
140D 0D01+        DC WS
140E 4007+        JMM FMUL
140F 14E0+        DC R,E,WS2
1410 0D2B
1411 0FD6
1412 4011+        JMM FSUB
1413 0D01+        DC WS,WS2,WS2
1414 0FD6
1415 0FD6
1416 D0AB+        LDA WS2  HOLD STEADY IF DENOM ZERO
1417 04A1+        SAZ 1
1418 0481+        SKP 1
1419 523A+        JMP SET
141A 43B7+        JMM LIF
141B 0D6C+        DC EU1,G,WS
141C 0D2D
141D 0D01
141E 4007+        JMM FMUL
141F 0D01+        DC WS,E,WS
1420 0D2B
1421 0D01
1422 4007+        JMM FMUL
1423 0D27+        DC C,C,C
1424 0D27
1425 0D27
1426 4011+        JMM FSUB
1427 0D27+        DC C,WS,WS
1428 0D01
1429 0D01
142A 400C+        JMM FDIV
142B 0D01+        DC WS,WS2,WS
142C 0FD6
142D 0D01
142E 400C+        JMM FDIV
142F 0D01+        DC WS,PI,WS
1430 0CFA
1431 0D01
1432 D00A+        LDA WS+1   HOLD STEADY ON EXCESSIVE CHANGE
1433 0901+        SRI 1
1434 04B1+        SAN 1
1435 523A+        JMP SET
1436 4045+        JMM FADD
1437 0D29+        DC D,WS,D
1438 0D01
1439 0D29
143A 401D+SET     JMM MOVE
143B 0D23+        DC A,EX1
143C 0D70
143D 401D+        JMM MOVE
143E 0D25+        DC B,EY1
143F 0D72
1440 42FC+        JMM RANGE
1441 0D29+        DC D
1442 40AC+        JMM TRIG
1443 0D29+        DC D
1444 4007+        JMM FMUL  CALC COMP OF ACCEL
1445 14DE+        DC W,SIN,EV1
1446 17F5
1447 0D6E
1448 4007+        JMM FMUL
1449 14DE+        DC W,COS,EU1
```

```
144A  17F7
144B  0D6C
144C  F0A9+        INC TEMP
144D  50AD+        JMP NEWT
144E  4007+        JMM FMUL   UPDATE POS AND VEL
144F  0D33+        DC Q,EU1,A
1450  0D6C
1451  0D23
1452  404D+        JMM HALF
1453  0D23+        DC A
1454  4045+        JMM FADD
1455  0D44+        DC U1,A,U1
1456  0D23
1457  0D44
1458  4007+        JMM FMUL
1459  0D44+        DC U1,Q,B
145A  0D33
145B  0D25
145C  4045+        JMM FADD
145D  0D48+        DC X1,B,X1
145E  0D25
145F  0D48
1460  4045+        JMM FADD   (REST OF VEL CHNG)
1461  0D44+        DC U1,A,U1
1462  0D23
1463  0D44
1464  4007+        JMM FMUL
1465  0D33+        DC Q,EV1,A
1466  0D6E
1467  0D23
1468  404D+        JMM HALF
1469  0D23+        DC A
146A  4045+        JMM FADD
146B  0D46+        DC V1,A,V1
146C  0D23
146D  0D46
146E  4007+        JMM FMUL
146F  0D46+        DC V1,Q,B
1470  0D33
1471  0D25
1472  4045+        JMM FADD
1473  0D4A+        DC Y1,B,Y1
1474  0D25
1475  0D4A
1476  4045+        JMM FADD
1477  0D46+        DC V1,A,V1
1478  0D23
1479  0D46
147A  42B6+        JMM BOUND
147B  0D48+        DC X1,XOFF
147C  0CEF
147D  52AB+        JMP HUMAN
147E  42B6+        JMM BOUND
147F  0D4A+        DC Y1,YOFF
1480  0CF1
1481  52AB+        JMP HUMAN
1482  42B6+        JMM BOUND
1483  0D5C+        DC X2,XOFF
1484  0CEF
1485  529E+        JMP CPU
1486  42B6+        JMM BOUND
1487  0D5E+        DC Y2,YOFF
1488  0CF1
1489  529E+        JMP CPU
148A  4011+        JMM FSUB
148B  0D48+        DC X1,X2,A   MISL CLOSE?
148C  0D5C
148D  0D23
```

```
148E D0AE+      LDA A+1
148F 0802+      ADI 2
1490 04B1+      SAN 1
1491 529A+      JMP WGIN
1492 4011+      JMM FSUB
1493 0D4A+      DC Y1,Y2.A
1494 0D5E
1495 0D23
1496 D0AE+      LDA A+1
1497 0803+      ADI 3
1498 04D1+      SAG 1
1499 529E+      JMP CPU
149A D0AF+WGIN  LDA GINI  WAIT FOR CROS HAIRS
149B 04A1+      SAZ 1
149C 529A+      JMP WGIN
149D 50B0+      JMP RECALC
149E 0D01+CPU   LDI 1
149F 4043+      JMM MODF
14A0 4020+      JMM MSG
14A1 0D5C+      DC X2,Y2,ZAP
14A2 0D5E
14A3 14E6
14A4 4020+      JMM MSG
14A5 0D48+      DC X1,Y1,QT
14A6 0D4A
14A7 14EE
14A8 40B1+HUM   JMM WAITP
14A9 4051+      JMM WIPE
14AA 50B2+      JMP SETUP
14AB 0D01+HUMAN LDI 1
14AC 4043+      JMM MODF
14AD 4020+      JMM MSG
14AE 0D5C+      DC X2,Y2,WIN
14AF 0D5E
14B0 14E9
14B1 4007+      JMM FMUL
14B2 14DE+      DC W,D1.5,W
14B3 14E2
14B4 14DE
14B5 52A8+      JMP HUM
14B6 22D3+BOUND STX BDX
14B7 0700+      LAX 0
14B8 62BD+      STA BAD1
14B9 0701+      LAX 1
14BA 62BE+      STA BAD2
14BB 62C5+      STA BAD3
14BC 4011+      JMM FSUB
14BD 0000+BAD1  DC 000
14BE 0000+BAD2  DC 000,BAA
14BF 14D1
14C0 D2D1+      LDA BAA
14C1 04D2+      SAG 2
14C2 4048+      JMM FNEG
14C3 14D1+      DC BAA
14C4 4011+      JMM FSUB
14C5 0000+BAD3  DC 000,BAA,BAA
14C6 14D1
14C7 14D1
14C8 4011+      JMM FSUB
14C9 14D1+      DC BAA,D.2,BAA
14CA 14F4
14CB 14D1
14CC D2D1+      LDA BAA
14CD C2D3+      LDX BDX
14CE 04D1+      SAG 1
14CF 07C2+      JMX 2
14D0 07C3+      JMX 3
         +*
```

```
14D1 0000+BAA   DC 0,0
14D2 0000
14D3 0000+BDX   DC 0
14D4 4833+D72.2 DC 72.2B7,7
14D5 0007
14D6 7170+D7.09 DC 7.09B3,3
14D7 0003
14D8 5666+D5.4  DC 5.4B3,3
14D9 0003
14DA 4CCC+D.15  DC .15B-2,-2
14DB FFFE
14DC 7800+D960. DC 960.B10,10
14DD 000A
14DE 0000+W     DC 0,0
14DF 0000
14E0 0000+R     DC 0,0
14E1 0000
14E2 6000+D1.5  DC 1.5B1,1
14E3 0001
14E4 6666+D.2   DC .2B-2,-2
14E5 FFFF
14E6 DAC1+ZAP   TXT,4 ZAP!
14E7 D0A1
14E8 0000+      DC 0
14E9 D9CF+WIN   TXT,7 YOU WIN
14EA D5A0
14EB D7C9
14EC CEA0
14ED 0000+      DC 0
14EE DEA0+QT    TXT,2 ^
14EF 0000+      DC 0
14F0 22FB+ZERO  STX ZX
14F1 DAFB+      LDA *ZX
14F2 04D2+      SAG 2
14F3 C2FB+      LDX ZX
14F4 07C1+      JMX 1
14F5 0600+      XXA
14F6 0540+      CLA
14F7 0740+      SAX 0
14F8 0741+      SAX 1
14F9 E2FB+      INC ZX
14FA 52F1+      JMP ZERO+1
14FB      +ZX   DS 1
          +*
14FC 2306+RANGE STX RGX   LIMIT ARG TO RANGE +-1
14FD 0700+      LAX 0
14FE 6301+      STA RAD1
14FF 6303+      STA RAD2
1500 4012+      JMM FRACT
1501 0000+RAD1  DC 000
1502 4082+      JMM NORM
1503 0000+RAD2  DC 000
1504 C306+      LDX RGX
1505 07C1+      JMX 1
1506      +RGX  DS 1
```

```
1507 2336+DFLOAT STX DFX  DBL FIXED B5 TO SGL FLOAT
1508 2336+       STX DFX
1509 0D05+       LDI 5
150A 6338+       STA FR+1
150B 0301+       LIX 1
150C 6339+       STA FR+2
150D 0300+       LIX 0
150E 6337+       STA FR
150F 4082+       JMM NORM
1510 1537+       DC FR  NORMALIZ UPPER HALF
1511 D337+       LDA FR
1512 04A1+       SAZ 1
1513 5324+       JMP USU
1514 D066+       LDA =-11
1515 6338+       STA FR+1
1516 D339+       LDA FR+2
1517 04D2+       SAG 2
1518 E338+       INC FR+1
1519 0C81+       LRN 1
151A 6337+       STA FR
151B 4082+       JMM NORM
151C 1537+       DC FR
151D C336+RET    LDX DFX
151E 0201+       INX 1
151F D337+       LDA FR
1520 0340+       SIX 0
1521 D338+       LDA FR+1
1522 0341+       SIX 1
1523 07C1+       JMX 1
1524 D338+USU    LDA FR+1
1525 0905+       SBI 5
1526 04B1+       SAN 1
1527 531D+       JMP RET
1528 0810+       ADI 16
1529 8379+       ADD LRN0
152A 632C+       STA SH3
152B D339+       LDA FR+2
152C 0C80+SH3    LRN 000
152D A337+       ORA FR
152E 6337+       STA FR
152F 04B1+       SAN 1
1530 531D+       JMP RET
1531 8068+       ADD =$4000
1532 04B2+       SAN 2
1533 4082+       JMM NORM
1534 1537+       DC FR
1535 531D+       JMP RET
          +*
1536      +DFX   DS 1
1537      +FR    DS 3
153A      +TEM   DS 1
          +*
153B 2336+DFIX   STX DFX
153C 0300+       LIX 0
153D 6337+       STA FR
153E 0301+       LIX 1
153F 0906+       SBI 6
1540 04B1+       SAN 1
1541 536E+       JMP MAX
1542 0810+       ADI 16
1543 04D1+       SAG 1
1544 5357+       JMP LOW
1545 633A+       STA TEM
1546 090F+       SBI 15
1547 0482+       SAN 2
1548 0540+       CLA
1549 534F+       JMP SH2+1
154A 0810+       ADI 16
```

```
154B 837B+        ADD  LLN
154C 634E+        STA  SH2
154D D337+        LDA  FR
154E 0C00+SH2     LLN  000
154F 6338+        STA  FR+1
1550 D37A+        LDA  ARS15
1551 933A+        SUB  TEM
1552 6354+        STA  SH1
1553 D337+        LDA  FR
1554 0CC0+SH1     ARS  000
1555 6337+        STA  FR
1556 531D+        JMP  RET
1557 04A1+LOW     SAZ  1
1558 5360+        JMP  LOLO
1559 D337+        LDA  FR
155A 0C01+        LLN  1
155B 6338+        STA  FR+1
155C D337+        LDA  FR
155D 0CCF+FIXUP ARS  15
155E 6337+        STA  FR
155F 531D+        JMP  RET
1560 080F+LOLO    ADI  15
1561 04B1+        SAN  1
1562 0484+        SKP  4
1563 0540+        CLA
1564 6337+        STA  FR
1565 6338+        STA  FR+1
1566 531D+        JMP  RET
1567 0100+        TWA
1568 837C+        ADD  ARS14
1569 636B+        STA  SH5
156A D337+        LDA  FR
156B 0CC0+SH5     ARS  000
156C 6338+        STA  FR+1
156D 535D+        JMP  FIXUP
156E D337+MAX     LDA  FR
156F 04B4+        SAN  4
1570 D086+        LDA  =$7FFF
1571 6337+        STA  FR
1572 D04E+        LDA  =$FFFF
1573 0483+        SKP  3
1574 D0B3+        LDA  =$8000
1575 6337+        STA  FR
1576 0D01+        LDI  1
1577 6338+        STA  FR+1
1578 531D+        JMP  RET
          +*
1579 0C80+LRN0  LRN  0
157A 0CCF+ARS15  ARS  15
157B 0C00+LLN   LLN  0
157C 0CCE+ARS14  ARS  14
          +*
157D 2399+DADD    STX  DAX
157E 0300+        LIX  0
157F 639A+        STA  DD   A+FIXB=C
1580 0301+        LIX  1
1581 639B+        STA  DD+1
1582 0701+        LAX  1
1583 6385+        STA  DPT
1584 433B+        JMM  DFIX
1585 0000+DPT     DC  000,DB
1586 159C
1587 C399+        LDX  DAX
1588 0202+        INX  2
1589 05E0+        REX  C
158A D39B+        LDA  DD+1
158B 839D+        ADD  DB+1
158C 0341+        SIX  1
```

```
158D D39A+        LDA  DD
158E 05D0+        REX  V
158F 01C0+        ADC
1590 839C+        ADD  DB
1591 0415+        SNV  5
1592 0180+        ONA
1593 6337+        STA  FR
1594 0241+        DNX  1
1595 2336+        STX  DFX
1596 536F+        JMP  MAX
1597 0340+        SIX  0
1598 07C1+        JMX  1
          +*
1599      +DAX    DS  1
159A      +DD     DS  2
159C      +DB     DS  2
          +*
159E 23B4+DAVER  STX  DHX   MEAN(A,B)=C
159F 0300+        LIX  0
15A0 0CC1+        ARS  1
15A1 63B5+        STA  DH
15A2 0301+        LIX  1
15A3 0CA1+        LRI  1
15A4 63B6+        STA  DH+1
15A5 0201+        INX  1
15A6 0300+        LIX  0
15A7 0CC1+        ARS  1
15A8 639A+        STA  DD
15A9 0301+        LIX  1
15AA 0CA1+        LRI  1
15AB 05E0+        REX  C
15AC 83B6+        ADD  DH+1
15AD 0201+        INX  1
15AE 0341+        SIX  1
15AF D3B5+        LDA  DH
15B0 01C0+        ADC
15B1 839A+        ADD  DD
15B2 0340+        SIX  0
15B3 07C1+        JMX  1
          +*
15B4      +DHX    DS  1
15B5      +DH     DS  2
```

```
15B7 23D0+LIE   STX LIX     LIE BRACKET OF TWO VECTORS
15B8 0700+      LAX 0
15B9 63C3+      STA LA1
15BA 0802+      ADI 2
15BB 63C7+      STA LA2
15BC 0701+      LAX 1
15BD 63C8+      STA LA3
15BE 0802+      ADI 2
15BF 63C4+      STA LA4
15C0 0702+      LAX 2
15C1 63CD+      STA LA5
15C2 4007+      JMM FMUL
15C3 0000+LA1   DC 000
15C4 0000+LA4   DC 000,LWS
15C5 15D1
15C6 4007+      JMM FMUL
15C7 0000+LA2   DC 000
15C8 0000+LA3   DC 000,LWS2
15C9 15D3
15CA 4011+      JMM FSUB
15CB 15D1+      DC LWS,LWS2
15CC 15D3
15CD 0000+LA5   DC 000
15CE C3D0+      LDX LIX
15CF 07C3+      JMX 3
         +*
15D0     +LIX   DS 1
15D1     +LWS   DS 2
15D3     +LWS2  DS 2
         +*
15D5 23EE+DOT   STX DOX   DOT PRODUCT OF TWO VECTORS
15D6 0700+      LAX 0
15D7 63F1+      STA DO1
15D8 0802+      ADI 2
15D9 63F5+      STA DO2
15DA 0701+      LAX 1
15DB 63F2+      STA DO3
15DC 0802+      ADI 2
15DD 63F6+      STA DO4
15DE 0702+      LAX 2
15DF 63FB+      STA DO5
15F0 4007+      JMM FMUL
15F1 0000+DO1   DC 000
15F2 0000+DO3   DC 000,LWS
15F3 15D1
15F4 4007+      JMM FMUL
15F5 0000+DO2   DC 000
15F6 0000+DO4   DC 000,LWS2
15F7 15D3
15F8 4045+      JMM FADD
15F9 15D1+      DC LWS,LWS2
15FA 15D3
15FB 0000+DO5   DC 000
15FC C3EE+      LDX DOX
15FD 07C3+      JMX 3
15EE     +DOX   DS 1
         +      END
```

```
                +*   TEKTRONIX PLOTTING ROUTINE
                +       ENTRY CRT,XPOS,YPOS,PKP1,BLEN2
                +       ENTRY XLOC,YLOC,MARK
                +       EXTRN PLOT,CALCOMP
                +       EXTRN MODE,QMODO,GINI,RDCORD
                +       EXTRN PKP,PAK
                +       EXTRN FADD,FSUB,FMUL,FDIV,FIX,FLOAT,NORM,FRACT
                +       EXTRN XOFF,YOFF,SCALE
15EF  20B4+CRT  STX PX
15F0  0700+     LAX 0
15F1  04A4+     SAZ 4
15F2  0901+     SBI 1
15F3  04A1+     SAZ 1
15F4  0482+     SKP 2
15F5  50B5+     JMP SWIBUF
15F6  50B6+     JMP NUBUF
15F7  0901+     SBI 1
15F8  04A1+     SAZ 1
15F9  0481+     SKP 1
15FA  50B7+     JMP FORGET
15FB  0300+     LIX 0
15FC  6061+     STA X
15FD  0301+     LIX 1
15FE  6062+     STA X+1
15FF  0201+     INX 1
1600  0300+     LIX 0
1601  62BF+     STA Y
1602  0301+     LIX 1
1603  62C0+     STA Y+1
1604  0701+     LAX 1
1605  62CB+     STA OP
1606  D2C1+     LDA IX
1607  62C5+     STA XL   SAVE OLD POSITION
1608  D2C6+     LDA IY
1609  62CA+     STA YL
160A  4011+     JMM FSUB
160B  16BD+     DC X,XOFF,IX
160C  0CEF
160D  16C1
160E  4011+     JMM FSUB
160F  16BF+     DC Y,YOFF,IY
1610  0CF1
1611  16C6
1612  4007+     JMM FMUL  CONVERT INCHES TO INCREMENTS
1613  16C1+     DC IX,SCALE,IX
1614  0DE4
1615  16C1
1616  D2C2+     LDA IX+1     *4  RESOLUTION
1617  0802+     ADI 2
1618  62C2+     STA IX+1
1619  4045+     JMM FADD MOVE ORIGIN TO LOWER LEFT CORNER OF SCREEN
161A  16C1+     DC IX,OX,IX
161B  16C3
161C  16C1
161D  4018+     JMM FIX
161E  16C1+     PTR IX  CONVERT OT FIXED POINT INCREMENTS
161F  4007+     JMM FMUL  SAME FOR Y COORD
1620  16C6+     DC IY,SCALE,IY
1621  0DE4
1622  16C6
1623  D2C7+     LDA IY+1
1624  0802+     ADI 2
1625  62C7+     STA IY+1
1626  4045+     JMM FADD
1627  16C6+     DC IY,OY,IY
1628  16C8
1629  16C6
162A  4018+     JMM FIX
```

```
162B 16C6+        PTR IY
162C D2C1+        LDA IX
162D 92C5+        SUB XL    CALC # DELAY CHARS
162E 0140+        ABA
162F 63B0+        STA MX
1630 D2C6+        LDA IY
1631 92CA+        SUB YL
1632 0140+        ABA
1633 63B1+        STA MY
1634 93B0+        SUB MX
1635 04D1+        SAG 1
1636 0540+        CLA
1637 83B0+        ADD MX
1638 63B0+        STA MX
1639 0540+        CLA
163A 04F0+        DIV
163B 0000+        DC 0,MX,DTIME
163C 17B0
163D 17B2
163E 04A6+        SAZ NOWAIT
163F 0100+        TWA
1640 63B0+        STA MX
1641 0D96+        LDI $96
1642 4058+        JMM PAK
1643 E3B0+        INC MX
1644 5241+        JMP *-3
1645 D2CB+NOWAIT LDA OP
1646 B08F+        ANA =-2
1647 0902+        SBI 2
1648 04A5+        SAZ 5
1649 0902+        SBI 2
164A 04A1+        SAZ 1
164B 5262+        JMP LEAF
164C 0540+        CLA
164D 0481+        SKP 1
164E 0D01+        LDI 1
164F 6396+        STA AUK
1650 4264+        JMM DRAW
1651 D2CB+        LDA OP
1652 04C1+        SLZ 1    IS MARKER WANTED
1653 0481+        SKP 1
1654 5262+        JMP LEAF
1655 E396+        INC AUK   FORCE DRAWING
1656 C0B8+        LDX =-6
1657 2397+DRABOX STX SCWAX
1658 D2C1+        LDA IX
1659 879E+        ADD DX+6,1
165A 62C1+        STA IX
165B D2C6+        LDA IY
165C 87A4+        ADD DY+6,1
165D 62C6+        STA IY
165E 4264+        JMM DRAW
165F C397+        LDX SCWAX
1660 0201+        INX 1
1661 5257+        JMP DRABOX
1662 C2BC+LEAF   LDX PX
1663 07C3+        JMX 3
         +*
1664 23A4+DRAW   STX DRX
1665 D2C1+        LDA IX
1666 04D1+        SAG 1
1667 0540+        CLA
1668 90B9+        SUB =4095
1669 04B1+        SAN 1
166A 0540+        CLA
166B 80B9+        ADD =4095
166C 63A5+        STA DIX
166D D2C6+        LDA IY
```

```
166E  04D2+     SAG 2
166F  04A1+     SAZ 1
1670  0540+     CLA
1671  90BA+     SUB =3120
1672  04B1+     SAN 1
1673  0540+     CLA
1674  80BA+     ADD =3120
1675  63A6+      STA DIY
1676  D3A5+     LDA DIX
1677  0C87+     LRN 7
1678  0820+     ADI $20
1679  63AA+     STA HX
167A  D3A5+     LDA DIX
167B  0C82+     LRN 2
167C  B0A3+     ANA =$1F
167D  0840+     ADI $40
167E  63AB+     STA LX
167F  D3A5+     LDA DIX
1680  B0BB+     ANA =3
1681  63A8+     STA XBYTE
1682  D3A6+     LDA DIY
1683  0C87+     LRN 7
1684  0820+     ADI $20
1685  63A7+     STA HY
1686  D3A6+     LDA DIY
1687  0C82+     LRN 2
1688  B0A3+     ANA =$1F
1689  0860+     ADI $60
168A  63A9+     STA LY
168B  D3A6+     LDA DIY
168C  B0BB+     ANA =3
168D  0C02+     LLN 2
168E  A3A8+     ORA XBYTE
168F  0860+     ADI $60
1690  63A8+     STA XBYTE
1691  D3AA+     LDA HX   DETERMINE WHICH BYTES NEED XMITING
1692  F3AF+     CAA LPOS+2  HI X DIFF
1693  0484+     SKP 4
1694  0483+     SKP 3
1695  0540+     CLA
1696  63AA+     STA HX  CLEAR UNNECESSARY BYTE
1697  0481+     SKP 1
1698  63AE+     STA LPOS+2  SAVE NEW VALUE
1699  D3A7+     LDA HY
169A  F3AC+     CAA LPOS
169B  0484+     SKP 4
169C  0483+     SKP 3
169D  0540+     CLA
169E  63A7+     STA HY
169F  0481+     SKP 1
16A0  63AC+     STA LPOS
16A1  D396+     LDA AUK  SHOULD LINE BE INVISIBLE
16A2  04D2+     SAG 2
16A3  0D9D+     LDI $9D US
16A4  4058+     JMM PAK
16A5  C094+     LDX =-5
16A6  D7AC+     LDA HY+5,1
16A7  23AF+     STX TRX
16A8  4058+     JMM PAK
16A9  C3AF+     LDX TRX
16AA  0201+     INX 1
16AB  52A6+     JMP *-5
16AC  D016+     LDA CALCOMP
16AD  04D1+     SAG 1
16AE  5BA4+     JMP *DRX
16AF  D396+     LDA AUK
16B0  0C01+     LLN 1
16B1  0802+     ADI 2
```

```
16B2 62B6+        STA PEN
16B3 4017+        JMM PLOT
16B4 16C1+        DC IX,IY
16B5 16C6
16B6 0000+PEN     DC 0
16B7 5BA4+        JMP *DRX
          +*
16B8 04A2+EDO     SAZ 2
16B9 0B46+        EDO 4,6
16BA 52B9+        JMP *-1
16BB 07C0+        JMX 0
          +*
16BC 0000+PX      DC 0
16BD 0000+X       DC 0,0
16BE 0000
16BF 0000+Y       DC 0,0
16C0 0000
          +XPOS   EQU X
16C1 0000+IX      DC 0,0
16C2 0000
16C3 4000+OX      DC 2048B12,12
16C4 000C
16C5 0000+XL      DC 0
          +YPOS   EQU Y
16C6 0000+IY      DC 0,0
16C7 0000
16C8 6180+OY      DC 1560B11,11
16C9 000B
16CA 0000+YL      DC 0
16CB 0000+OP      DC 0
16CC 16CE+PKP1    DC BF1
16CD 1732+PKP2    DC BF2
16CE      +BF1    DS 100
1732      +BF2    DS 100
1796 0000+AUK     DC 0
1797 0000+SCWAX DC 0
1798 0002+DX      DC 2,-4,0,4,0,-2
1799 FFFC
179A 0000
179B 0004
179C 0000
179D FFFE
179E 0002+DY      DC 2,0,-4,0,4,-2
179F 0000
17A0 FFFC
17A1 0000
17A2 0004
17A3 FFFE
17A4 0000+DRX     DC 0
17A5 0000+DIX     DC 0
17A6 0000+DIY     DC 0
17A7 0000+HY      DC 0
17A8 0000+XBYTE DC 0
17A9 0000+LY      DC 0
17AA 0000+HX      DC 0
17AB 0000+LX      DC 0
17AC 0000+LPOS DC 0,0,0
17AD 0000
17AE 0000
17AF 0000+TRX     DC 0
17B0 0000+MX      DC 0
17B1 0000+MY      DC 0
17B2 05DC+DTIME DC 1500
          +*
17B3 D2CC+NUBUF LDA PKP1
17B4 0C01+        LLN 1   INITIALIZE AT CURRENT BUFFER
17B5 60BC+        STA PKP
17B6 D04E+FORGET LDA =-1   DESTROY PREVIOUSLY REMEMBERED POSITION
```

```
17B7 63AC+        STA LPOS
17B8 63AF+        STA LPOS+2
17B9 62C5+        STA XL
17BA 62CA+        STA YL
17BB 07C1+        JMX 1
17BC 0501+SWIBUF SEX H  GIVE CURRENT BUFFER TO SCOPE
17BD C08D+        LDX =$18
17BE D0BE+        LDA =SCOPEOUT
17BF 0740+        SAX 0
17C0 D0BC+        LDA PKP
17C1 92CC+        SUB PKP1
17C2 92CC+        SUB PKP1
17C3 0801+        ADI 1
17C4 B08F+        ANA =-2
17C5 63EE+        STA BLEN  RECORD LENGTH
17C6 0742+        SAX 2
17C7 D2CD+        LDA PKP2
17C8 62C1+        STA IX
17C9 D2CC+        LDA PKP1
17CA 62CD+        STA PKP2
17CB 0741+        SAX 1
17CC D2C1+        LDA IX
17CD 62CC+        STA PKP1
17CE 0540+        CLA
17CF 0743+        SAX 3
17D0 0D08+        LDI 8  TURN ON SCOPE INTERRUPT
17D1 0F46+        ECO 4,6
17D2 53D1+        JMP *-1
17D3 05C1+        REX H
17D4 C2BC+        LDX PX
17D5 53B3+        JMP NUBUF
          +*
17D6 D0AF+SCOPEOUT LDA GINI
17D7 04A7+        SAZ 7
17D8 40BF+        JMM RDCORD
17D9 D3FF+        LDA BLEN2
17DA 63EF+        STA BLEN
17DB D2BD+        LDA XPOS
17DC 63F0+        STA XLOC
17DD D2BF+        LDA YPOS
17DE 63F2+        STA YLOC
17DF D0C0+        LDA QMODO
17E0 04A7+        SAZ 7
17E1 0D04+        LDI 4
17E2 0F46+        ECO 4,6
17E3 53E2+        JMP *-1
17E4 13E5+        JRL *+1
17E5 0B46+        EDO 4,6
17E6 13E5+        JRL *-1
17E7 13E5+        JRL *-2
17E8 0D96+        LDI $96  RESTART IN REP MODE
17E9 0B46+        EDO 4,6
17EA 53E9+        JMP *-1
17EB C2CD+        LDX PKP2
17EC D3EE+        LDA BLEN
17ED 13D6+        JRL SCOPEOUT
17EE 0000+BLEN DC 0
17EF      +BLEN2 DS 1
17F0      +XLOC DS 2
17F2      +YLOC DS 2
17F4      +MARK DS 1
          +       END
```

```
          +*  SINGLE PRECISION FLOATING SINE-COSINE
          +*
          +      ENTRY TRIG,SIN,COS
          +      EXTRN FRACT
          +      EXTRN NORM
          +      EXTRN FIX,FLOAT
17F5      +SIN DS 2
17F7      +COS DS 2
17F9 20C1+TRIG STX TX
17FA 0300+     LIX 0
17FB 60C2+     STA ANG
17FC 0301+     LIX 1
17FD 60C3+     STA ANG+1
17FE 4012+     JMM FRACT
17FF 1834+     DC ANG
1800 D234+     LDA ANG
1801 6236+     STA X   ANGLE TO ARG OF SERIES CALCULATOR
1802 4212+     JMM SICO  DO TRIG SERIES
1803 60C4+     STA SIN
1804 D234+     LDA ANG  ROTATE BY 90 DEG FOR COSINE
1805 8068+     ADD =$4000
1806 6236+     STA X
1807 4212+     JMM SICO
1808 60C5+     STA COS
1809 0540+     CLA
180A 60C6+     STA SIN+1
180B 60C7+     STA COS+1
180C 4082+     JMM NORM  NORMALIZE RESULTS
180D 17F5+     DC SIN
180E 4082+     JMM NORM
180F 17F7+     DC COS
1810 C233+     LDX TX
1811 07C1+     JMX 1
          +*
1812 D236+SICO LDA X  CALC SIN X
1813 05D0+      REX V  CONVERT X TO +-90 SCALED TO +-1
1814 0C41+     ALS 1
1815 0412+     SNV 2  NO OVERFLOW IF IN +-90
1816 80B3+     ADD =$8000
1817 0100+     TWA
1818 6236+     STA X
1819 04A1+     SAZ 1
181A 0481+     SKP 1
181B 07C0+     JMX 0    0,180 ARE ZERO
181C D236+     LDA X
181D 04F0+     MPY
181E 0000+     DC 0,X,T
181F 1836
1820 1838
1821 6237+     STA Z  Z=X*X
1822 04F0+     MPY    CALC SIN(X)=X+X*(C1+Z*(C3+Z*C5))
1823 0000+     DC 0,C5,T
1824 183B
1825 1838
1826 0CC3+     ARS 3  SET BINARY POINT
1827 823A+     ADD C3
1828 04E0+     MPY
1829 0000+     DC 0,Z,T
182A 1837
182B 1838
182C 8239+     ADD C1
182D 04E0+     MPY
182E 0000+     DC 0,X,T
182F 1836
1830 1838
1831 8236+     ADD X
1832 07C0+     JMX 0
1833 0000+TX   DC 0
```

```
1834  0000+ANG   DC 0,0
1835  0000
1836  0000+X     DC 0
1837  0000+Z     DC 0
1838  0000+T     DC 0
1839  4900+C1    DC $4900   .570317077B0
183A  ADD0+C3    DC -$5230  -.6421013799B0
183B  4993+C5    DC $4993   .07185141382B-3
          +      END
```

```
               +*   C R T SYMBOL DRAWING ROUTINE
               +*     JMM SCRIBE
               +*     DC X,Y.SIZE,MSG
               +*
               +      ENTRY SCRIBE
               +      EXTRN CRT,FADD,FSUB,FMUL,FDIV,FLOAT,FIX,NORM,FRACT
               +*
183C 22B7+SCRIBE STX SCX
183D 0300+      LIX 0
183E 62AF+      STA XQ
183F 0301+      LIX 1
1840 62B0+      STA XQ+1
1841 0201+      INX 1
1842 0300+      LIX 0
1843 62B1+      STA YQ
1844 0301+      LIX 1
1845 62B2+      STA YQ+1
1846 0701+      LAX 1
1847 624C+      STA SIZE
1848 62A8+      STA SIZE2
1849 0702+      LAX 2
184A 6315+      STA PTR
184B 400C+      JMM FDIV  CALC SIZE OF TEKPOINT
184C 0000+SIZE  DC 0.D7,TEKPT
184D 18B3
184E 18B5
184F DB15+CHLP  LDA *PTR
1850 04A1+      SAZ 1
1851 0482+      SKP 2
1852 C2B7+      LDX SCX
1853 07C4+      JMX 4
1854 0C88+      LRN 8
1855 425A+      JMM CRTDRAW
1856 DB15+      LDA *PTR
1857 425A+      JMM CRTDRAW
1858 E315+      INC PTR
1859 524F+      JMP CHLP
               +*
185A 2316+CRTDRAW STX DRX
185B B09C+      ANA =$FF
185C 09A0+      SBI $A0
185D 04B1+      SAN 1
185E 0481+      SKP 1
185F 07C0+      JMX 0
1860 B0C8+      ANA =$3F
1861 0600+      XXA
1862 D71C+      LDA VECTOR,1
1863 0C8B+      LRN 11
1864 04D1+      SAG 1
1865 52A6+      JMP DUNNE
1866 0100+      TWA
1867 631B+      STA CT
1868 D71C+      LDA VECTOR,1
1869 B0C9+      ANA =$7FF
186A 80CA+      ADD =DFINE
186B 80CB+      ADD =DFINE-1
186C 6317+      STA DPTR
186D 0D04+      LDI 4
186E 62A0+      STA PENY
186F D317+GBYTE LDA DPTR
1870 0CC1+      ARS 1
1871 0600+      XXA
1872 0700+      LAX 0
1873 0401+      SNC 1
1874 0C08+      LLN 8
1875 0C88+      LRN 8
1876 6318+      STA CHAR
1877 0C84+      LRN 4     X VALS 0 TO 6  8 TO 15
```

```
1878 F0CC+        CAA =7    ARF     0 TO 6 -1 TO -8
1879 527E+        JMP NEGX
187A 5280+        JMP POSX
187B 0D04+        LDI 4    X=7 IS NOP BUT RAISE PEN NEXT MOVE
187C 62A0+        STA PENY
187D 52A3+        JMP INCH
187E 0100+NEGX    TWA
187F 0807+        ADI 7
1880 62B8+POSX    STA DX
1881 D318+        LDA CHAR
1882 B0CD+        ANA =$F
1883 090A+        SBI 10
1884 04D2+        SAG 2
1885 080A+        ADI 10
1886 0481+        SKP 1
1887 0100+        TWA
1888 62BA+        STA DY
1889 4081+        JMM FLOAT
188A 18B8+        DC DX
188B 4081+        JMM FLOAT
188C 18BA+        DC DY
188D 4007+        JMM FMUL  SCALE TO SIZE
188E 18B8+        DC DX,TEKPT,DX
188F 18B5
1890 18B8
1891 4007+        JMM FMUL
1892 18BA+        DC DY,TEKPT,DY
1893 18B5
1894 18BA
1895 4045+        JMM FADD
1896 18AF+        DC XQ,DX,XR
1897 18B8
1898 18BC
1899 4045+        JMM FADD
189A 18B1+        DC YQ,DY,YR
189B 18BA
189C 18BE
189D 401F+        JMM CRT
189E 18BC+        DC XR,YR
189F 18BE
18A0 0000+PENY    DC 0
18A1 0D02+        LDI 2
18A2 62A0+        STA PENY
18A3 E317+INCH    INC DPTR
18A4 E31B+        INC CT
18A5 526F+        JMP GBYTE
18A6 4045+DUNNE   JMM FADD
18A7 18AF+        DC XQ
18A8 0000+SIZE2   DC 0,XQ
18A9 18AF
18AA 401F+        JMM CRT
18AB 18AF+        DC XQ,YQ,4
18AC 18B1
18AD 0004
18AE 5B16+        JMP *DRX
          +*
18AF 0000+XQ      DC 0,0
18B0 0000
18B1 0000+YQ      DC 0,0
18B2 0000
18B3 7000+D7      DC 7B3,3
18B4 0003
18B5 0000+TEKPT   DC 0,0
18B6 0000
18B7 0000+SCX     DC 0
18B8 0000+DX      DC 0,0
18B9 0000
18BA 0000+DY      DC 0,0
```

```
18BB 0000
18BC 0000+XR    DC 0,0
18BD 0000
18BE 0000+YR    DC 0,0
18BF 0000
```

```
          +*   CALCOMP SYMBOL GENERATING ROUTINE
          +*
          +*      JMM SYMBOL
          +*      DC X,Y,MSG
          +*
          +*      ...
          +*MSG   TXT,N BLAHBLAHBLAH
          +*      DC 0
          +*
          +       ENTRY SYMBOL
          +       EXTRN PLOT
          +*
18C0 2312+SYMBOL STX SYX
18C1 0300+       LIX 0  GET X (IN INCREMENTS)
18C2 6313+       STA X
18C3 0201+       INX 1
18C4 0300+       LIX 0
18C5 6314+       STA Y
18C6 0701+       LAX 1  GET LOCATION OF MESSAGE
18C7 6315+       STA PTR
18C8 DB15+ZLP    LDA *PTR  GET NEXT WORD OF MESSAGE
18C9 04A1+       SAZ 1  EXIT IF ZERO
18CA 0482+       SKP 2
18CB C312+       LDX SYX
18CC 07C3+       JMX 3
18CD 0C88+       LRN 8  PLOT HIGH BYTE
18CE 42D3+       JMM DRAW
18CF DB15+       LDA *PTR
18D0 F315+       INC PTR
18D1 42D3+       JMM DRAW  PLOT LOW BYTWE
18D2 52C8+       JMP ZLP
          +*
18D3 2316+DRAW   STX DRX
18D4 09A0+       SBI $A0  BLANK IS FIRST CHAR
18D5 B0C8+       ANA =$3F  MOD 64
18D6 0600+       XXA  GET TABLE ENTRY FOR THIS SYMBOL
18D7 D71C+       LDA VECTOR,1
18D8 0C8B+       LRN 11  GET NUMBER OF SEGMENTS IN CHAR
18D9 04D1+       SAG 1
18DA 530A+       JMP DONE
18DB 0100+       TWA
18DC 631B+       STA CT
18DD D71C+       LDA VECTOR,1
18DE B0C9+       ANA =$7FF  GET BYTE ADDRESS FIRST SEGMENT
18DF 80CA+       ADD =DFINE
18E0 80CB+       ADD =DFINE-1
18E1 6317+       STA DPTR
18E2 0D04+       LDI 4
18E3 6304+       STA PEN
18E4 D317+DDD    LDA DPTR  GET BYTE CONTAINING NEXT SEGMENT
18E5 0CC1+       ARS 1  GET WORD ADDRESS
18E6 0600+       XXA
18E7 0700+       LAX 0 GET WORD
18E8 0401+       SNC 1  PICK PROPER BYTE
18E9 0C08+       LLN 8
18EA 0C88+       LRN 8
18EB 6318+       STA CHAR
18EC 0C84+       LRN 4   GET X PART OF BYTE
18ED 0907+       SBI 7  X=7  IS NOOP AND RAISE PEN FOR NEXT SEGMENT
18EE 04A1+       SAZ 1
18EF 0483+       SKP 3
18F0 0D04+       LDI 4
18F1 6304+       STA PEN
18F2 5307+       JMP INC
18F3 0807+       ADI 7
18F4 0C01+       LLN 1
18F5 8313+       ADD X
18F6 6319+       STA XP  SAVE NEW POS
18F7 D318+       LDA CHAR
```

```
18F8 B0CD+       ANA =$F   GET Y BYTE
18F9 090A+       SBI 10  0-10 IS 0-10  11-15 IS -1 THRU -5
18FA 04D2+       SAG 2
18FB 080A+       ADI 10
18FC 0481+       SKP 1
18FD 0100+       TWA
18FE 0C01+       LLN 1
18FF 8314+       ADD Y
1900 631A+       STA YP  SAVE NEW Y POS
1901 4017+       JMM PLOT
1902 1919+       DC XP,YP
1903 191A
1904 0000+PEN    DC 0
1905 0D02+       LDI 2  SET PEN TO DOWN FOR NEXT SEGMENT
1906 6304+       STA PEN
1907 E317+INC    INC DPTR  MOVE TO NEXT BYTE
1908 E31B+       INC CT
1909 52E4+       JMP DDD
190A 0D0E+DONE   LDI 14  LEAVE PEN BY LOWER RIGHT CORNER OF CHAR
190B 8313+       ADD X
190C 6313+       STA X
190D 4017+       JMM PLOT
190E 1913+       DC X,Y,4
190F 1914
1910 0004
1911 5B16+       JMP *DRX
          +*
1912 0000+SYX    DC 0
1913 0000+X      DC 0
1914 0000+Y      DC 0
1915 0000+PTR    DC 0
1916 0000+DRX    DC 0
1917 0000+DPTR   DC 0
1918 0000+CHAR   DC 0
1919 0000+XP     DC 0
191A 0000+YP     DC 0
191B 0000+CT     DC 0
191C 0144+VECTOR DC $0144,$0172,$294F
191D 0172
191E 294F
191F 5972+       DC $5972,$812F,$0172
1920 812F
1921 0172
1922 4969+       DC $4969,$1167,$2127
1923 1167
1924 2127
1925 212B+       DC $212B,$411D,$2916
1926 411D
1927 2916
1928 3144+       DC $3144,$111B,$294A
1929 111B
192A 294A
192B 1125+       DC $1125,$48B9,$28C2
192C 48B9
192D 28C2
192E 40C7+       DC $40C7,$68CF,$30DC
192F 68CF
1930 30DC
1931 48E2+       DC $48E2,$60EB,$18F7
1932 60EB
1933 18F7
1934 80FA+       DC $80FA,$610A,$595C
1935 610A
1936 595C
1937 6190+       DC $6190,$197D,$293F
1938 197D
1939 293F
193A 1980+       DC $1980,$6983,$0183
```

```
193B 6983
193C 0183
193D 4001+      DC $4001,$6809,$4016
193E 6809
193F 4016
1940 381F+      DC $381F,$3825,$302C
1941 3825
1942 302C
1943 5032+      DC $5032,$303C,$3042
1944 303C
1945 3042
1946 3048+      DC $3048,$304E,$1854
1947 304E
1948 1854
1949 2857+      DC $2857,$205C,$6060
194A 205C
194B 6060
194C 486C+      DC $486C,$6075,$5881
194D 6075
194E 5881
194F 608C+      DC $608C,$2098,$389C
1950 2098
1951 389C
1952 18A3+      DC $18A3,$28A6,$28AB
1953 28A6
1954 28AB
1955 28B0+      DC $28B0,$20B5,$2154
1956 20B5
1957 2154
1958 0172+      DC $0172,$2158,$0190
1959 2158
195A 0190
195B 0000+      DC $0000
195C 0006+DFINE DC $0006,$1737,$4640,$4303
195D 1737
195E 4640
195F 4303
1960 3746+      DC $3746,$4534,$4341,$3000
1961 4534
1962 4341
1963 3000
1964 0434+      DC $0434,$0407,$3746,$3717
1965 0407
1966 3746
1967 3717
1968 0601+      DC $0601,$1030,$4100,$0737
1969 1030
196A 4100
196B 0737
196C 4641+      DC $4641,$3000,$4000,$0434
196D 3000
196E 4000
196F 0434
1970 0407+      DC $0407,$4700,$0434,$0407
1971 4700
1972 0434
1973 0407
1974 4746+      DC $4746,$3717,$0601,$1030
1975 3717
1976 0601
1977 1030
1978 4143+      DC $4143,$3300,$0704,$4447
1979 3300
197A 0704
197B 4447
197C 4010+      DC $4010,$3020,$2717,$3747
197D 3020
197E 2717
```

```
197F 3747
1980 4130+        DC $4130,$1001,$0200,$0703
1981 1001
1982 0200
1983 0703
1984 4714+        DC $4714,$4040,$0007,$0007
1985 4040
1986 0007
1987 0007
1988 2447+        DC $2447,$4000,$0740,$4730
1989 4000
198A 0740
198B 4730
198C 1001+        DC $1001,$0617,$3746,$4130
198D 0617
198E 3746
198F 4130
1990 7000+        DC $7000,$4700,$0434,$0407
1991 4700
1992 0434
1993 0407
1994 3746+        DC $3746,$4534,$3010,$0106
1995 4534
1996 3010
1997 0106
1998 1737+        DC $1737,$4641,$3031,$304B
1999 4641
199A 3031
199B 304B
199C 0004+        DC $0004,$3404,$0737,$4645
199D 3404
199E 0737
199F 4645
19A0 3424+        DC $3424,$4001,$1030,$4143
19A1 4001
19A2 1030
19A3 4143
19A4 3414+        DC $3414,$0506,$1737,$4620
19A5 0506
19A6 1737
19A7 4620
19A8 2707+        DC $2707,$4747,$4130,$1001
19A9 4747
19AA 4130
19AB 1001
19AC 0207+        DC $0207,$0720,$4707,$1024
19AD 0720
19AE 4707
19AF 1024
19B0 3047+        DC $3047,$0740,$7000,$4707
19B1 0740
19B2 7000
19B3 4707
19B4 2420+        DC $2420,$2447,$0747,$0040
19B5 2447
19B6 0747
19B7 0040
19B8 3010+        DC $3010,$0106,$1737,$4641
19B9 0106
19BA 1737
19BB 4641
19BC 3010+        DC $3010,$3020,$2716,$0617
19BD 3020
19BE 2716
19BF 0617
19C0 3746+        DC $3746,$4401,$0040,$0617
19C1 4401
19C2 0040
```

```
19C3 0617
19C4 3746+          DC $3746,$4534,$1434,$4341
19C5 4534
19C6 1434
19C7 4341
19C8 3010+          DC $3010,$0107,$0343,$3337
19C9 0107
19CA 0343
19CB 3337
19CC 3047+          DC $3047,$0704,$3443,$4130
19CD 0704
19CE 3443
19CF 4130
19D0 1001+          DC $1001,$4637,$1706,$0110
19D1 4637
19D2 1706
19D3 0110
19D4 3041+          DC $3041,$4334,$1403,$0747
19D5 4334
19D6 1403
19D7 0747
19D8 0014+          DC $0014,$0506,$1737,$4645
19D9 0506
19DA 1737
19DB 4645
19DC 3414+          DC $3414,$0301,$1030,$4143
19DD 0301
19DE 1030
19DF 4143
19E0 3401+          DC $3401,$1030,$4146,$3717
19E1 1030
19E2 4146
19E3 3717
19E4 0604+          DC $0604,$1333,$4421,$2523
19E5 1333
19E6 4421
19E7 2523
19E8 0343+          DC $0343,$0343,$0343,$2315
19E9 0343
19EA 0343
19EB 2315
19EC 3123+          DC $3123,$3511,$0047,$4031
19ED 3511
19EE 0047
19EF 4031
19F0 3647+          DC $3647,$0011,$1607,$0110
19F1 0011
19F2 1607
19F3 0110
19F4 3041+          DC $3041,$4334,$1405,$0617
19F5 4334
19F6 1405
19F7 0617
19F8 3746+          DC $3746,$3727,$282B,$0242
19F9 3727
19FA 282B
19FB 0242
19FC 7044+          DC $7044,$041B,$2021,$1110
19FD 041B
19FE 2021
19FF 1110
1A00 2010+          DC $2010,$1121,$2010,$1517
1A01 1121
1A02 2010
1A03 1517
1A04 7037+          DC $7037,$354C,$2C29,$490C
1A05 354C
1A06 2C29
```

```
1A07  490C
1A08  2C29+      DC $2C29,$0920,$2111,$1020
1A09  0920
1A0A  2111
1A0B  1020
1A0C  7013+      DC $7013,$2324,$1413,$2725
1A0D  2324
1A0E  1413
1A0F  2725
1A10  4016+      DC $4016,$2736,$0301,$1020
1A11  2736
1A12  0301
1A13  1020
1A14  4300+      DC $4300,$2670,$4620,$7002
1A15  2670
1A16  4620
1A17  7002
1A18  4270+      DC $4270,$4404,$4103,$4501
1A19  4404
1A1A  4103
1A1B  4501
1A1C  4305+      DC $4305,$0617,$2736,$3513
1A1D  0617
1A1E  2736
1A1F  3513
1A20  2270+      DC $2270,$1011,$2120,$101B
1A21  1011
1A22  2120
1A23  101B
1A24  2021+      DC $2021,$1110,$2070,$1323
1A25  1110
1A26  2070
1A27  1323
1A28  2414+      DC $2414,$1300
1A29  1300
          +       END
```

```
                +*  SINGLE PRECISION FLOATING POINT ARITHMATIC
                +*
                +       ENTRY FSUB,FADD,FMUL,FDIV
                +       ENTRY FLOAT,FIX,NORM,FNEG,FRACT
                +       ENTRY MOVE
1A2A  2280+FSUB STX FX     FLOATING SUBTRACT
1A2B  0201+     INX 1
1A2C  0300+     LIX 0
1A2D  05D0+     REX V
1A2E  0100+     TWA  COMPLEMENT
1A2F  0416+     SNV 6
1A30  0301+     LIX 1
1A31  0801+     ADI 1
1A32  6282+     STA SMAND+1
1A33  D068+     LDA =$4000
1A34  6281+     STA SMAND
1A35  523E+     JMP ADREST+2
1A36  6281+     STA SMAND
1A37  523C+     JMP ADREST
                +*
1A38  2280+FADD STX FX
1A39  0201+     INX 1  GET SUMMAND
1A3A  0300+     LIX 0
1A3B  6281+     STA SMAND
1A3C  0301+ADREST LIX 1
1A3D  6282+     STA SMAND+1
1A3E  C280+     LDX FX
1A3F  0300+     LIX 0
1A40  6283+     STA ADEND
1A41  0301+     LIX 1
1A42  6284+     STA ADEND+1
1A43  9282+     SUB SMAND+1 COMPARE EXPONENTS
1A44  F090+     CAA =0
1A45  5248+     JMP SHIFS
1A46  5252+     JMP SHIFA
1A47  5264+     JMP DOAD  EXPONENTS EQUAL
1A48  0910+SHIFS SBI 16  SUMMAND MUST BE SCALED
1A49  0481+     SAN 1  IS SUMMAND INSIGNIF^
1A4A  5279+     JMP RESULT  YES,NO OP
1A4B  0810+     ADI 16
1A4C  A285+     ORA ARS  CREATE SHIFT INSTRUCTION
1A4D  624F+     STA *+2
1A4E  D281+     LDA SMAND
1A4F  0CC0+     ARS 0
1A50  6281+     STA SMAND
1A51  5264+     JMP DOAD
1A52  0100+SHIFA TWA  ADDEND MUST BE SCALED
1A53  0910+     SBI 16
1A54  04B7+     SAN 7
1A55  C280+     LDX FX
1A56  0202+     INX 2
1A57  D281+     LDA SMAND  SUMMAND IS ANSWER
1A58  0340+     SIX 0
1A59  D282+     LDA SMAND+1
1A5A  0341+     SIX 1
1A5B  07C1+     JMX 1
1A5C  0810+      ADI 16
1A5D  A285+     ORA ARS
1A5E  6260+     STA *+2
1A5F  D283+     LDA ADEND
1A60  0CC0+     ARS 0  DO CALCULATED SHIFT
1A61  6283+     STA ADEND.
1A62  D282+     LDA SMAND+1
1A63  6284+     STA ADEND+1
1A64  05F0+DOAD REX C,V
1A65  D283+     LDA ADEND  DO ADDITION
1A66  8281+     ADD SMAND
1A67  6283+     STA ADEND
```

```
1A68 041E+       SNV 14  CHECK FOR OVERFLOW
1A69 0560+       LSB    IVERT SIGN BIT AND INSERT CARRY BIT AS
1A6A 6286+       STA TEMP  HIGH MAGNITUDE BIT
1A6B D283+       LDA ADEND
1A6C 80B3+       ADD =$8000
1A6D 0C31+       LLC 1
1A6E 6283+       STA ADEND
1A6F D286+       LDA TEMP
1A70 80B3+       ADD =$8000
1A71 0570+       SSB
1A72 D283+       LDA ADEND
1A73 0CA2+       LRI 2
1A74 6283+       STA ADEND
1A75 F284+       INC ADEND+1
1A76 0500+       NOP
1A77 4287+       JMM NORM
1A78 1A83+       PTR ADEND
1A79 C280+RESULT LDX FX
1A7A 0202+       INX 2
1A7B D283+       LDA ADEND
1A7C 0340+       SIX 0
1A7D D284+       LDA ADEND+1
1A7E 0341+       SIX 1
1A7F 07C1+       JMX 1
         +*
1A80     +FX     DS 1
1A81     +SMAND  DS 2
1A83     +ADEND  DS 2
1A85 0CC0+ARS    ARS 0
1A86     +TEMP   DS 1
         +*
1A87 0300+NORM   LIX 0
1A88 04A9+       SAZ 9
1A89 05D0+       REX V
1A8A 0C41+       ALS 1
1A8B 0411+       SNV 1
1A8C 07C1+       JMX 1
1A8D 0340+       SIX 0  FLOATING POINT NORMALIZE
1A8E 0301+       LIX 1
1A8F 0901+       SBI 1
1A90 0341+       SIX 1
1A91 5287+       JMP NORM
1A92 0341+       SIX 1
1A93 07C1+       JMX 1
         +*
1A94 22D5+FDIV   STX FDX  FLOATING DIVIDE
1A95 0300+       LIX 0
1A96 04A1+       SAZ 1
1A97 0484+       SKP 4
1A98 0202+ZRET   INX 2
1A99 0340+       SIX 0
1A9A 0341+       SIX 1
1A9B 07C1+       JMX 1
1A9C 62D6+       STA DEND
1A9D 0301+       LIX 1
1A9E 62D7+       STA DEND+1
1A9F 0201+       INX 1
1AA0 0301+       LIX 1
1AA1 62D9+       STA DSOR+1
1AA2 0300+       LIX 0
1AA3 62D8+       STA DSOR
1AA4 05DC+       REX V,R,S
1AA5 04D7+       SAG 7
1AA6 0100+       TWA
1AA7 0508+       SEX R
1AA8 0413+       SNV 3
1AA9 D068+       LDA =1B1
1AAA E2D9+       INC DSOR+1
```

```
1AAB 0500+       NOP
1AAC 62D8+       STA DSOP
1AAD D2D6+       LDA DEND
1AAE 04D8+       SAG 8
1AAF 05D0+       REX V
1AB0 0504+       SEX S
1AB1 0100+       TWA
1AB2 0413+       SNV 3
1AB3 D068+       LDA =1B1
1AB4 F2D7+       INC DEND+1
1AB5 0500+       NOP
1AB6 62D6+       STA DEND
1AB7 92D8+       SUB DSOR
1AB8 62DB+       STA HI
1AB9 04B1+       SAN 1
1ABA 62D6+       STA DEND  TAKEN CARE OF OVERFLO BIT
1ABB D2D6+       LDA DEND  DO REST OF DIIDE
1ABC 04F0+       DIV
1ABD 0000+       DC 0,LOW,DSOR
1ABE 1ADA
1ABF 1AD8
1AC0 62D6+       STA DEND  SAVE QUOTIENT
1AC1 D2DB+       LDA HI  OVERFLOW^
1AC2 04B6+       SAN NOVERF
1AC3 D2D6+       LDA DEND
1AC4 0C81+       LRN 1
1AC5 8068+       ADD =1B1  STICK IN OVERFLOW BIT
1AC6 62D6+       STA DEND
1AC7 F2D7+       INC DEND+1  ADJUST EXPONENT
1AC8 0500+       NOP
1AC9 D2D7+NOVERF LDA DEND+1  DIFFENCE EXPONENTS
1ACA 92D9+       SUB DSOP+1
1ACB C2D5+       LDX FDX  SAVE RESULT
1ACC 0202+       INX 2
1ACD 0341+       SIX 1
1ACE D2D6+       LDA DEND
1ACF 0421+       SNR 1
1AD0 0100+       TWA
1AD1 0431+       SNS 1
1AD2 0100+       TWA
1AD3 0340+       SIX 0
1AD4 07C1+       JMX 1
          +*
1AD5      +FDX DS 1
1AD6      +DEND DS 2
1AD8      +DSOR DS 2
1ADA      +LOW  DS 1
1ADB      +HI   DS 1
          +*
1ADC 2306+FMUL STX FMX  FLOATING MULTIPLY
1ADD 0300+       LIX 0
1ADE 6307+       STA CAND  MULTIPLICAND
1ADF 0301+       LIX 1
1AE0 6308+       STA CAND+1
1AE1 0201+       INX 1
1AE2 0300+       LIX 0
1AE3 6309+       STA LIER  MULTIPLIER
1AE4 0301+       LIX 1
1AE5 630A+       STA LIER+1
1AE6 D307+       LDA CAND
1AE7 05D0+       REX V
1AE8 04E0+       MPY
1AE9 0000+       DC 0,LIER,CAND
1AEA 1B09
1AEB 1B07
1AEC 6309+      STA LIER  SAVE HIGH PART
1AED 0415+       SNV 5  -1*-1 GIVES OVERFLOW
1AEE D068+       LDA =$4000
```

```
1AEF 6309+        STA LIER
1AF0 F30A+        INC LIER+1
1AF1 52FE+        JMP ADEXP
1AF2 52FE+        JMP ADEXP
1AF3 0C41+        ALS 1  CHECK IF NORMALIZED
1AF4 0411+        SNV 1
1AF5 52FE+        JMP ADEXP
1AF6 D307+        LDA CAND  GET MAGNITUDE BIT TO SHIF IN
1AF7 0C22+        LLI 2
1AF8 D309+        LDA LIER
1AF9 0C21+        LLI 1
1AFA 6309+        STA LIER
1AFB D30A+        LDA LIER+1
1AFC 0901+        SBI 1
1AFD 630A+        STA LIER+1
1AFE D309+ADEXP LDA LIER  CHECK FO ZERO PRODUCT
1AFF 0201+        INX 1
1B00 0340+        SIX 0
1B01 04A2+        SAZ 2
1B02 D308+        LDA CAND+1  ADD EXPONENTS
1B03 830A+        ADD LIER+1
1B04 0341+        SIX 1
1B05 07C1+        JMX 1
          +*
1B06      +FMX   DS 1
1B07      +CAND  DS 2
1B09      +LIER  DS 2
          +*
1B0B 2314+FLOAT STX FOX  CONVERT TO FLOATING POINT
1B0C 0D0F+       LDI 15  SET TRIAL EXPONENT
1B0D 0341+       SIX 1
1B0E 0700+       LAX 0
1B0F 6311+       STA *+2
1B10 4287+       JMM NORM
1B11 0000+       DC 0
1B12 C314+       LDX FOX
1B13 07C1+       JMX 1
1B14 0000+FOX    DC 0
          +*
1B15 2336+FIX    STX FFIX  CONVERT TO FIXED POINT
1B16 0300+       LIX 0
1B17 6335+       STA F
1B18 0301+       LIX 1
1B19 6336+       STA F+1
1B1A 0910+       SBI 16
1B1B 04B1+       SAN 1  CHECK IF TOO BIG
1B1C 07C1+       JMX 1
1B1D 0810+       ADI 16
1B1E 04DD+       SAG 13  SKIP IF BIG
1B1F 04A4+       SAZ 4
1B20 0540+ZRO    CLA  RESULT IS ZERO
1B21 0340+       SIX 0
1B22 0341+       SIX 1
1B23 07C1+       JMX 1
1B24 D335+       LDA F  CHECK IF -1
1B25 90B3+       SUB =$8000
1B26 04A1+       SAZ 1
1B27 5320+       JMP ZRO
1B28 0901+       SBI 1  SET TO -1
1B29 0340+       SIX 0
1B2A 0540+       CLA
1B2B 5322+       JMP ZRO+2
1B2C 0100+       TWA
1B2D 8337+       ADD ARSF  CREATE SHIFT INSTRUCTION
1B2E 6330+       STA *+2
1B2F D335+       LDA F
1B30 0CC0+       ARS 0
1B31 0340+       SIX 0
```

```
1B32  0540+       CLA
1B33  0341+       SIX  1
1B34  07C1+       JMX  1
           +*
1B35  0000+F       DC  0
1B36       +FFIX  DS  1
1B37  0CCF+ARSF  ARS  15
           +*
1B38  05D0+FNEG  REX  V
1B39  0300+       LIX  0
1B3A  0100+       TWA
1B3B  0416+       SNV  6
1B3C  D068+       LDA  =$4000
1B3D  0340+       SIX  0
1B3E  0301+       LIX  1
1B3F  0801+       ADI  1
1B40  0341+       SIX  1
1B41  07C1+       JMX  1
1B42  0340+       SIX  0
1B43  90CE+       SUB  =$C000
1B44  04A1+       SAZ  1
1B45  07C1+       JMX  1
1B46  D0B3+       LDA  =$8000
1B47  0340+       SIX  0
1B48  0301+       LIX  1
1B49  0901+       SBI  1
1B4A  0341+       SIX  1
1B4B  07C1+       JMX  1
           +*
1B4C  0301+FRACT LIX  1   CALC FRACTION OF NUMBER
1B4D  04D1+       SAG  1   LOOK AT EXPONENT
1B4E  5356+       JMP  LITL
1B4F  0910+       SBI  16   MAG>=1. IF TOO BIG SET TO ZERO
1B50  04B1+       SAN  1
1B51  5358+       JMP  ZERO
1B52  0810+       ADI  16
1B53  8365+       ADD  LLN   GENERATE SHIFT INSTRUCTION
1B54  6360+       STA  SHIFT   UNITS B WILL BECOME SIGN
1B55  535F+       JMP  SCALE
1B56  080F+LITL  ADI  15   MAG<=1, IF TOO SMALL SET TO ZERO
1B57  04D4+       SAG  4
1B58  0540+ZERO  CLA
1B59  0340+       SIX  0
1B5A  0341+       SIX  1
1B5B  07C1+       JMX  1
1B5C  0100+       TWA
1B5D  8366+       ADD  ARS15
1B5E  6360+       STA  SHIFT
1B5F  0300+SCALE LIX  0
1B60  0000+SHIFT HLT  0
1B61  0340+       SIX  0
1B62  0540+       CLA
1B63  0341+       SIX  1
1B64  07C1+       JMX  1
           +*
1B65  0C00+LLN   LLN  0
1B66  0CCF+ARS15 ARS  15
           +*
1B67  0300+MOVE  LIX  0
1B68  636F+       STA  MTP
1B69  0301+       LIX  1
1B6A  0201+       INX  1
1B6B  0341+       SIX  1
1B6C  D36F+       LDA  MTP
1B6D  0340+       SIX  0
1B6E  07C1+       JMX  1
1B6F  0000+MTP   DC  0
           +      END
```

```
            +*  CALCOMP PLOTTTING ROUTINE
            +*
            +       ENTRY PLOT
            +       ORG $380
0380  20CF+PLOT  STX PLTX
0381  0300+      LIX 0  GET X
0382  60D0+      STA X
0383  0CCF+      ARS 15  CONVERT TO DOUBLE PRECISION
0384  60D1+      STA X+1
0385  0201+      INX 1
0386  0300+      LIX 0
0387  60D2+      STA Y  SAVE Y IN DOUBLE PRECISION
0388  0CCF+      ARS 15
0389  60D3+      STA Y+1
038A  0701+      LAX 1  GET IPEN
038B  60D4+      STA PEN
038C  04B1+      SAN 1  NEG MEANS INITIALIZE
038D  50D5+      JMP NORM
038E  0802+       ADI 2
038F  04B1+       SAN 1
0390  53E0+       JMP INIT
0391  C0D6+       LDX =-42  RETURN PEN TO ORIGIN
0392  D453+LIMIT LDA XRAST+42,1
0393  05E0+       REX C  SET COORD TO MAX IF BEYOND MAX
0394  84D7+       ADD MX+42,1
0395  D459+       LDA XRAST+43,1
0396  01C0+       ADC
0397  84D8+       ADD MX+43,1
0398  04B6+       SAN 6
0399  D4D7+       LDA MX+42,1
039A  0100+       TWA
039B  6453+       STA XRAST+42,1
039C  D4D8+       LDA MX+43,1
039D  0180+       ONA
039E  6459+       STA XRAST+43,1
039F  0206+       INX 6
03A0  020F+       INX 15
03A1  5392+       JMP LIMIT
03A2  0D01+       LDI 1
03A3  60D9+       STA ERRY  SET UP -X AND -Y COMMANDS
03A4  0D08+      LDI 8
03A5  60DA+       STA ERRX
03A6  0D10+       LDI $10  RAISE PEN
03A7  0B20+       EDO 2,0
03A8  53A7+       JMP *-1
03A9  60DB+       STA PPOS
03AA  40DC+      JMM WAITP
03AB  0540+      CLA
03AC  60DD+      STA CWORD
03AD  C0D6+       LDX =-42
03AE  05E0+DECR  REX C  DECREMENT COORD
03AF  D453+      LDA XRAST+42,1
03B0  0904+      SBI 4
03B1  6453+       STA XRAST+42,1
03B2  D459+       LDA XRAST+43,1
03B3  0401+       SNC 1
03B4  0481+       SKP 1
03B5  0901+       SBI 1
03B6  6459+       STA XRAST+43,1
03B7  04B3+       SAN 3  NO OP IF BELOW ZERO
03B8  D0DD+       LDA CWORD
03B9  A401+       ORA ERRX+42,1  MERGE IN COMMAND
03BA  60DD+       STA CWORD
03BB  0206+       INX 6
03BC  020F+       INX 15
03BD  53AE+       JMP DECR
03BE  D0DD+       LDA CWORD
03BF  04A3+       SAZ 3  NO OP MEANS DONE
```

```
03C0 0B20+       EDO 2,0
03C1 53C0+       JMP *-1
03C2 53AB+       JMP DECR-3
03C3 0D20+       LDI $20
03C4 0B20+       EDO 2,0
03C5 53C4+       JMP *-1
03C6 40DC+       JMM WAITP
03C7 C0DE+       LDX =-15
03C8 0D09+       LDI 9
03C9 0B20+       EDO 2,0
03CA 53C9+       JMP *-1
03CB 0201+       INX 1
03CC 53C9+       JMP *-3
03CD 0D10+       LDI $10
03CE 0B20+       EDO 2,0
03CF 53CE+       JMP *-1
03D0 40DC+       JMM WAITP
03D1 C0DE+       LDX =-15
03D2 0D06+       LDI 6
03D3 0B20+       EDO 2,0
03D4 53D3+       JMP *-1
03D5 0201+       INX 1
03D6 53D3+       JMP *-3
03D7 D0DF+       LDA XMAX
03D8 08C8+       ADI 200
03D9 0600+       XXA
03DA 0D04+       LDI $4  SPACE OUT BEYOND MAX
03DB 0B20+       EDO 2,0
03DC 53DB+       JMP *-1
03DD 0241+       DNX 1
03DE 53DB+       JMP *-3
03DF 53F4+       JMP CLEAR-2
03E0 0100+INIT   TWA  INITIALIZE%-1 NORMAL,-2 REVERSED COORDS
03E1 0801+       ADI 1
03E2 60E0+       STA MEER  MEER=1 FOR REVERSED
03E3 D0D0+       LDA X  X IS DENOMMINATOR OF SCALE FACTOR
03E4 60E1+       STA PROG
03E5 D0D2+       LDA Y  Y IS NUMERATOR
03E6 0C02+       LLN 2  TIMES 4
03E7 60E2+       STA RASTER
03E8 D04E+       LDA =-1 SET NEGATIVE OF MAX COORD VALUES
03E9 60E3+       STA MX+1
03EA 60E4+       STA MY+1
03EB D0E5+       LDA =$4480 =-4*12000  X GETS THE BIG MAX
03EC 60E6+       STA MX
03ED D0E7+       LDA =-4200
03EE 60E8+       STA MY
03EF 0D10+       LDI $10  COMMAND PEN UP
03F0 0B20+       EDO 2,0
03F1 53F0+       JMP *-1
03F2 60DB+       STA PPOS  REMEMBER THAT PEN IS UP
03F3 40DC+       JMM WAITP
03F4 C0D6+       LDX =-42
03F5 0540+       CLA
03F6 6402+CLEAR  STA ERRX2+42,1
03F7 64E9+       STA OX+42,1
03F8 64EA+       STA OX+43,1
03F9 64EB+       STA XPROG+42,1
03FA 64EC+       STA XPROG+43,1
03FB 6421+       STA XPROG2+42,1
03FC 6424+       STA XPROG2+43,1
03FD 6466+       STA XRASTP+42,1
03FE 6468+       STA XRASTP+43,1
03FF 6453+       STA XRAST+42,1
0400 67B6+       STA XRAST+43,1
0401 0206+       INX 6
0402 020F+       INX 15
0403 50ED+       JMP CLEAR
```

```
0404 637A+       STA XMAX
0405 637B+       STA XPOS
0406 C375+EXIT   LDX PLTX
0407 07C3+       JMX 3
          +*
0408 D370+NORM   LDA MEER  REVERSE COORDS
0409 04D1+       SAG 1
040A 048B+       SKP 11
040B D391+       LDA Y
040C 63A9+       STA T
040D D37C+       LDA X
040E 0100+       TWA
040F 6391+       STA Y
0410 0CCF+       ARS 15
0411 6392+       STA Y+1
0412 D3A9+       LDA T
0413 637C+       STA X   -Y TO X
0414 0CCF+       ARS 15   X TO Y
0415 637D+       STA X+1
0416 D376+       LDA PEN
0417 04A1+       SAZ 1
0418 522B+       JMP PLT
0419 C3DB+       LDX =-42  SET ORIGIN
041A D7A6+SORG   LDA X+42.1
041B 0100+       TWA
041C 63AE+       STA Q
041D 0CCF+       ARS 15
041E 63AF+       STA Q+1
041F D7AA+       LDA XPROG+42.1
0420 05E0+       REX C
0421 83AE+       ADD Q
0422 67A8+       STA OX+42,1
0423 D7AB+       LDA XPROG+43,1
0424 01C0+       ADC
0425 83AF+       ADD Q+1
0426 67A9+       STA OX+43,1
0427 0206+       INX 6
0428 020F+       INX 15
0429 521A+       JMP SORG
042A 5206+       JMP EXIT
          +*
042B B3C2+PLT    ANA =-2
042C 0902+       SBI 2  DETERMINE IF PEN SHOULD BE UP OR DOWN
042D 04A5+       SAZ 5
042E 0902+       SBI 2
042F 04A1+       SAZ 1
0430 0000+       HLT 0  HALT IF UNKNOWN PEN VALUE
0431 0D10+       LDI $10  PEN UP
0432 0481+       SKP 1
0433 0D20+       LDI $20  DOWN PEN
0434 936F+       SUB PPOS  COMPARE WITH CURRENT POSITION
0435 04A5+       SAZ 5
0436 836F+       ADD PPOS  DIFFERENT SO ISSUE PEN COMMAND
0437 636F+       STA PPOS
0438 0B20+       EDO 2,0
0439 5238+       JMP *-1
043A 4368+       JMM WAITP
043B C3DB+       LDX =-42
043C 05E0+SCALE  REX C  CALC ABS POSITION IN PROGRAM UNITS
043D D7A6+       LDA X+42,1
043E 87A8+       ADD OX+42,1  ADD ORIGIN
043F 67AA+       STA XPROG+42,1
0440 D7A7+       LDA X+43,1
0441 01C0+       ADC
0442 87A9+       ADD OX+43,1
0443 67AB+       STA XPROG+43,1
0444 D7AA+       LDA XPROG+42,1  CALC DIRECTION OF MOTION
0445 97B2+       SUB XPROG2+42,1
```

```
0446 67B4+        STA XDIR+42,1
0447 05E4+        REX S,C ABSOLUTE VALUE,SAVE SIGN
0448 D7AB+        LDA XPROG+43,1
0449 04B4+        SAN 4
044A 63AA+        STA T+1
044B D7AA+        LDA XPROG+42,1
044C 63A9+        STA T
044D 0488+        SKP 8
044E 0504+         SEX S
044F D7AA+        LDA XPROG+42,1
0450 0100+        TWA
0451 63A9+        STA T
0452 D7AB+        LDA XPROG+43,1
0453 0180+        ONA
0454 01C0+        ADC
0455 63AA+        STA T+1
0456 D3A9+        LDA T
0457 0C21+        LLI 1
0458 0C81+        LRN 1
0459 63A9+        STA T
045A D3AA+        LDA T+1
045B 0C21+        LLI 1
045C 63AA+        STA T+1
045D D3A9+        LDA T  TIMES NUMERATOR
045E 04E0+        MPY
045F 0500+        NOP
0460 0572+        PTR RASTER
0461 05A6+        PTR S
0462 63A7+        STA S+1
0463 D3AA+        LDA T+1
0464 04E0+        MPY
0465 0500+        NOP
0466 0572+        PTR RASTER
0467 05A9+        PTR T
0468 63AA+        STA T+1
0469 D3A9+        LDA T
046A 83A7+        ADD S+1
046B 63A7+        STA S+1
046C 04B1+        SAN 1
046D 5271+        JMP *+4
046E 83CD+        ADD =$8000
046F 63A7+        STA S+1
0470 E3AA+        INC T+1
0471 D3AA+        LDA T+1
0472 04F0+        DIV  DIVIDE BY DENOMINATOR
0473 0500+        NOP
0474 05A7+        PTR S+1
0475 0571+        PTR PROG
0476 67AD+        STA PXS+43,1  NEW POS SCALED TO RASTER UNITS,HI PART
0477 D3A7+        LDA S+1
0478 04F0+        DIV
0479 0500+        NOP
047A 05A6+        PTR S
047B 0571+        PTR PROG
047C 67AC+        STA PXS+42,1  LO PART
047D 05E0+        REX C
047E D7AD+        LDA PXS+43,1
047F 0CA1+        LRI 1
0480 67AD+        STA PXS+43,1
0481 D7AC+        LDA PXS+42,1
0482 0C01+        LLN 1
0483 0CA1+        LRI 1
0484 67AC+        STA PXS+42,1
0485 0437+        SNS 7  STICK SIGN BACK ON
0486 05E0+        REX C
0487 0100+        TWA
0488 67AC+        STA PXS+42,1
0489 D7AD+        LDA PXS+43,1
```

```
048A 0180+         ONA
048B 01C0+         ADC
048C 67AD+         STA PXS+43,1
048D D7B5+         LDA XRAST+42,1  COMPUTE DIRECTION FROM PEN TO END POINT
048E 97AC+         SUB PXS+42,1
048F 67B0+         STA ERRX+42,1
0490 0206+         INX 6
0491 020F+         INX 15
0492 523C+         JMP SCALE
0493 D39F+         LDA YDIR  COMPUTE SLOPE ERROR TO CURRENT PEN POS
0494 04E0+         MPY
0495 0500+         NOP
0496 0587+         PTR ERRX2
0497 05A9+         PTR T
0498 D38A+         LDA XDIR
0499 04E0+         MPY
049A 0500+         NOP
049B 059C+         PTR ERRY2
049C 05AA+         PTR T+1
049D D3AA+         LDA T+1
049E 93A9+         SUB T
049F 6374+         STA DSLOPE
04A0 D39F+         LDA YDIR
04A1 04B7+         SAN 7
04A2 0D04+         LDI 4
04A3 63A5+         STA DN
04A4 0D02+         LDI 2
04A5 6378+         STA YCOM
04A6 D38A+         LDA XDIR
04A7 0C02+         LLN 2
04A8 0487+         SKP 7
04A9 D3B6+         LDA =-4
04AA 63A5+         STA DN
04AB 0D01+         LDI 1
04AC 6378+         STA YCOM
04AD D38A+         LDA XDIR
04AE 0C02+         LLN 2
04AF 0100+         TWA
04B0 63A6+         STA S  COMPUTE CHANGES IN DSLOPE FOR VARIOUS
04B1 63A8+         STA S+2  PEN MOVEMENTS
04B2 D38A+         LDA XDIR
04B3 04B7+         SAN 7
04B4 0D04+         LDI 4
04B5 6390+         STA DM
04B6 0D04+         LDI 4
04B7 6379+         STA XCOM
04B8 D39F+         LDA YDIR
04B9 0C02+         LLN 2
04BA 0487+         SKP 7
04BB D3B6+         LDA =-4
04BC 6390+         STA DM
04BD 0D08+         LDI 8
04BE 6379+         STA XCOM
04BF D39F+         LDA YDIR
04C0 0C02+         LLN 2
04C1 0100+         TWA
04C2 0100+         TWA
04C3 63A7+         STA S+1
04C4 83A8+         ADD S+2
04C5 63A8+         STA S+2
04C6 D386+         LDA ERRX  COMPUTE DISTANCE TO ENDPOINT
04C7 0140+         ABA
04C8 6373+         STA DR
04C9 D39B+         LDA ERRY
04CA 0140+         ABA
04CB 8373+         ADD DR
04CC 6373+         STA DR
04CD C3DB+UPDATE LDX =-42
```

```
04CE D7B0+       LDA ERRX+42,1
04CF 67B1+       STA ERRX2+42,1
04D0 D7B7+       LDA XRASTP+42,1
04D1 67B5+       STA XRAST+42,1  UPDATE FROM LAST MOTION
04D2 D7B8+       LDA XRASTP+43,1
04D3 67B6+       STA XRAST+43,1
04D4 0206+       INX 6
04D5 020F+       INX 15
04D6 52CE+       JMP UPDATE+1
04D7 C3B9+       LDX =-3  FIND MOVEMENT THAT RESULTS IN MINIMUM
04D8 D7A9+       LDA S+3,1  SLOPE ERROR
04D9 8374+       ADD DSLOPE
04DA 0140+       ABA
04DB 67AE+       STA U+3,1
04DC 0201+       INX 1
04DD 52D8+       JMP *-5
04DE 0540+       CLA  START BUILDING COMMAND
04DF 6377+       STA CWORD
04E0 D3AC+       LDA U+1
04E1 F3AB+       CAA U
04E2 52FB+       JMP TRYY  TRY U,U+2
04E3 0500+       NOP
04E4 F3AD+       CAA U+2
04E5 52F1+       JMP BOTH
04E6 0500+       NOP
04E7 D3A7+XSTEP LDA S+1  STEP IN X DIRECTION IS BEST
04E8 8374+       ADD DSLOPE
04E9 6374+       STA DSLOPE
04EA D386+       LDA ERRX
04EB 8390+       ADD DM
04EC 6386+       STA ERRX
04ED D379+       LDA XCOM
04EE 8377+       ADD CWORD
04EF 6377+       STA CWORD
04F0 5308+       JMP COMMON
04F1 D3A8+BOTH  LDA S+2  STEP IN X AND  Y BEST
04F2 8374+       ADD DSLOPE
04F3 6374+       STA DSLOPE
04F4 D39B+       LDA ERRY
04F5 83A5+       ADD DN
04F6 639B+       STA ERRY
04F7 D378+       LDA YCOM
04F8 8377+       ADD CWORD
04F9 6377+       STA CWORD
04FA 52EA+       JMP XSTEP+3
04FB D3AB+TRYY  LDA U
04FC F3AD+       CAA U+2
04FD 52F1+       JMP BOTH
04FE 0500+       NOP
04FF D3A6+YSTEP LDA S   STEP IN Y DIRECTION IS BEST
0500 8374+       ADD DSLOPE
0501 6374+       STA DSLOPE
0502 D39B+       LDA ERRY
0503 83A5+       ADD DN
0504 639B+       STA ERRY
0505 D378+       LDA YCOM
0506 8377+       ADD CWORD
0507 6377+       STA CWORD
0508 D386+COMMON LDA ERRX  HOW FAR FROM END POI NT NOW?
0509 0140+       ABA
050A 636E+       STA TEMP
050B D39B+       LDA ERRY
050C 0140+       ABA
050D 836E+       ADD TEMP
050E F373+       CAA DR  ARE WE CLOSER?
050F 535A+       JMP END  NO SO DONE
0510 6373+       STA DR
0511 C3DB+       LDX =-42  ARE X AND Y WITHIN LIMITS?
```

```
0512 D7B0+LIMITS LDA ERRX+42,1
0513 97B1+       SUB ERRX2+42,1
0514 636E+       STA TEMP
0515 05E0+       REX C
0516 87B5+       ADD XRAST+42,1
0517 67B7+       STA XRASTP+42,1
0518 D36E+       LDA TEMP
0519 04B2+       SAN 2
051A 0540+       CLA
051B 0481+       SKP 1
051C D3B4+       LDA =-1
051D 01C0+       ADC
051E 87B6+       ADD XRAST+43,1
051F 67B8+       STA XRASTP+43,1
0520 05C4+       REX S
0521 D7BA+       LDA DM+42,1
0522 04B1+       SAN 1
0523 0504+       SEX S
0524 05E0+      REX C
0525 D7B7+      LDA XRASTP+42,1  COMPARE NEW POS WITH MAX
0526 87AE+       ADD MX+42,1
0527 63A9+       STA T
0528 D7B8+       LDA XRASTP+43,1
0529 01C0+       ADC
052A 87AF+       ADD MX+43,1
052B 0431+       SNS 1
052C 0486+       SKP 6
052D 63AA+       STA T+1
052E D3A9+       LDA T
052F 05E0+       REX C
0530 0804+       ADI 4
0531 D3AA+       LDA T+1
0532 01C0+       ADC
0533 04B4+       SAN 4
0534 D377+SMASH LDA CWORD  REMOVE BAD MOTION FROM WORD
0535 B7B9+       ANA XMASK+42,1
0536 6377+       STA CWORD
0537 5349+       JMP INX
0538 05E0+       REX C
0539 D7B7+       LDA XRASTP+42,1
053A 083C+       ADI 60
053B 63A9+       STA T
053C D7B8+       LDA XRASTP+43,1  CHECK IF BELOW -15 (*4)
053D 01C0+       ADC
053E 0437+       SNS 7
053F 63AA+       STA T+1  NO MOTION IF JUST REENTERING PLOTTABLE AREA
0540 D3A9+       LDA T
0541 05E0+       REX C
0542 83B6+       ADD =-4
0543 D3AA+       LDA T+1
0544 01C0+       ADC
0545 0901+       SBI 1
0546 04B1+       SAN 1
0547 0481+       SKP 1
0548 5334+       JMP SMASH  BELOW SO NO MOTION
0549 0206+INX    INX 6
054A 020F+       INX 15
054B 5312+       JMP LIMITS
054C D377+       LDA CWORD  DO COMMAND IF NON ZERO
054D 04A2+       SAZ 2
054E 0B20+       EDO 2,0
054F 534E+       JMP *-1
0550 0C82+       LRN 2
0551 04A7+       SAZ 7
0552 0901+       SBI 1
0553 04A2+       SAZ 2
0554 D3B4+       LDA =-1
0555 0481+       SKP 1
```

```
0556 0D01+        LDI 1
0557 837B+        ADD XPOS
0558 637B+        STA XPOS
0559 52CD+        JMP UPDATE
055A C3DB+END     LDX =-42
055B D7AA+        LDA XPROG+42,1 SAVE FINAL POSITION
055C 67B2+        STA XPROG2+42,1
055D D7AB+        LDA XPROG+43,1
055E 67B3+        STA XPROG2+43,1
055F 0206+        INX 6
0560 020F+        INX 15
0561 535B+        JMP END+1
0562 D37B+        LDA XPOS
0563 937A+        SUB XMAX
0564 04B2+        SAN 2
0565 D37B+        LDA XPOS
0566 637A+        STA XMAX
0567 5206+        JMP EXIT
          +*
0568 D36D+WAITP LDA PENW
0569 0901+        SBI 1
056A 04A1+        SAZ 1
056B 5369+        JMP *-2
056C 07C0+        JMX 0
          +*
056D 3000+PENW  DC $3000
056E      +TEMP  DS 1
056F      +PPOS  DS 1
0570      +MEER  DS 1
0571      +PROG  DS 1
0572      +RASTER DS 1
0573      +DR    DS 1
0574      +DSLOPE DS 1
0575      +PLTX  DS 1
0576      +PEN   DS 1
0577      +CWORD DS 1
0578      +YCOM  DS 1
0579      +XCOM  DS 1
057A      +XMAX  DS 1
057B      +XPOS  DS 1
          +*   X VARIABLES
057C      +X     DS 2
057E      +OX    DS 2
0580      +XPROG DS 2
0582      +PXS   DS 2
0584      +MX    DS 2
0586      +ERRX  DS 1
0587      +ERRX2 DS 1
0588      +XPROG2 DS 2
058A      +XDIR  DS 1
058B      +XRAST DS 2
058D      +XRASTP DS 2
058F 0003+XMASK DC $3
0590      +DM    DS 1
          +*   Y VARIABLES
0591      +Y     DS 2
0593      +OY    DS 2
0595      +YPROG DS 2
0597      +PYS   DS 2
0599      +MY    DS 2
059B      +ERRY  DS 1
059C      +ERRY2 DS 1
059D      +YPROG2 DS 2
059F      +YDIR  DS 1
05A0      +YRAST DS 2
05A2      +YRASTP DS 2
05A4 000C+YMASK DC $C
05A5      +DN    DS 1
```

```
             +*
05A6         +S        DS 3
05A9         +T        DS 2
05AB         +U        DS 3
05AE         +Q        DS 2
             +         END
05B0  0074
05B1  12A5
05B2  5400
05B3  5000
05B4  FFFF
05B5  FFF2
05B6  FFFC
05B7  FFF5
05B8  4000
05B9  FFFD
05BA  FFF6
05BB  2000
05BC  0D86
05BD  0D70
05BE  FFEC
05BF  7FFF
05C0  FFF4
05C1  3000
05C2  FFFE
05C3  0000
05C4  FFFB
05C5  00FF
05C6  127E
05C7  2710
05C8  FF8D
05C9  001F
05CA  0200
05CB  0186
05CC  6000
05CD  8000
05CE  FFFA
05CF  0FFF
05D0  0C30
05D1  0003
05D2  0018
05D3  17D6
05D4  003F
05D5  07FF
05D6  195C
05D7  195B
05D8  0007
05D9  000F
05DA  C000
05DB  FFD6
05DC  FFF1
05DD  4480
05DE  EF98
```