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SECTION 1

INTRODUCTION

This document is an unsolicited proposal describing the establishment of an advanced photographic-processing laboratory and a program of research, development, and testing of refined techniques in air/liquid bearing film processing. The data in this proposal were prepared by the technical staff of the Photographic Systems Group, [redacted] STAT
STAT [redacted] for the U.S. Government.

1.1 SCOPE

This proposal covers the technical details of the proposed program, a plan of accomplishment, and [redacted] qualifications to perform. STAT

1.2 OBJECTIVES

The proposed research program will establish design criteria for film processing techniques based on the [redacted] air/liquid bearing STAT
processing concept. The vehicle for proving and refining the design now in
STAT existence will be the [redacted] HTA-5 processor, to be provided for this program as GFE.

While the primary objective of the program is to determine the basic design criteria as a means of advancing the design and efficiency of the air/liquid bearing transport system, [redacted] will not restrict STAT
its effort to this goal. The technical areas discussed in this subsection establish the basic research parameters which will be enlarged as the research effort reveals promising avenues of investigation.

Company-sponsored design efforts carried on since completion of the HTA-5 processor, combined with the research and investigations planned for the proposed program, are expected to yield very favorable performance improvements in the listed areas as well as in other areas that become apparent during the program.

A brief summary of the work to be accomplished within the 12-month program period is given below:

1) A GFE cleanroom will be installed at the [redacted] STAT facilities of [redacted]. STAT A cleanroom environment is essential to the sensitometric performance and evaluation of the processor; no such facility exists at any other firm. In addition to being provided by the government at no cost to [redacted] STAT all costs connected with cleanroom installation will be borne by the government. [redacted] STAT will be responsible for its procurement and installation.

Approx. 18,000 sq. ft

2) The air/liquid bearing film-transport system will be improved under the basic company-sponsored research program now being conducted. Findings will be used as a basis for program enlargement. Important research areas include the investigation of air/liquid bearing geometry and air-liquid energy levels to provide stable "in-solution" and "in-air" film transportation. Investigation of other film-transport system aspects include vacuum capstans, film threading, and the minimization of film stresses by efficient torque control.

3) All film-processing factors will be exhaustively studied to optimize sensitometric performance. These factors will include, but will not necessarily be limited to, selection of plumbing materials and configurations, solution filtration, controllable development, densitometric instrumentation, process chemistry, gamma requirements, and film drying.

4) Present processor construction will be evaluated and improved, with these specific objectives as a goal: ease of maintenance, size reduction, and improved configuration from a human-factors standpoint.

STAT As in all [redacted] processors, modular design will be an important feature; major component modularity is considered to be vital for efficient disassembly and reassembly when rapid machine deployment is necessary, and for economical logistics and maintenance.

5) Processor reliability will be a major area of research. It is recognized that maximum machine availability and the safe handling of irreplaceable original film are essential; the operating components will be considered both individually and in terms of interface. In critical reliability areas, component redundancy and automatic standby switchover will be considered.

6) The performance needs of the processor will also be evaluated in the areas of film splicing, air-squeegee performance, power consumption, and processor power and function control.

7) Support documentation will be provided in the form of monthly letter-type reports and periodic technical reports. The monthly reports will briefly describe the program activities of the reporting period, the anticipated activities for the following period, liaison activities between the contractor and the customer, and an accounting of funds expended. The periodic technical reports will be furnished at the completion of each significant research phase; the scope will include performance results, conclusions, and recommendations.

1.3 PROBLEM BACKGROUND

Historically, continuous film-processing has consisted basically of moving exposed material, under tension, through a standard sequence of operations on a series of rollers. The program has been preset and is contingent on fixed sensitometric criteria. [redacted] has been continuously engaged in film-processing research for more than 25 years. STAT

Primary goals have been to improve on film output quality and equipment reliability. In achieving these goals, [redacted] has been responsible for the development of many well-known designs which others have emulated. STAT

From the standpoint of practical economics, [redacted] and its competitors have had to engineer processors within the quality limits imposed by roller-type film transports and fixed-program processing. These quality limitations, however minimized by judicious design, imply a certain amount of degradation due to the abrasive action of the film-transport system and less-than-optimum selection of film-processing parameters. Additional limitations have existed for many years because of limited knowledge in the areas of contaminant control, process-chemistry applications, hydrodynamics, and the application of sophisticated electronic techniques to photographic-process control. STAT

1.4 PROBLEM SOLUTION

STAT [redacted] has developed proprietary techniques and hardware to overcome the limitations on processed film quality imposed by conventional processor design. This claim is based on demonstrably advanced equipment such as the EH-49, the HTA-5, and the Super Levitron film processors. Each of these processors is based on an air/liquid bearing film transport in which the film is transported on cushions of air or liquid, under minimum stress, thus insuring virtual freedom from scratches or dimensional distortion. Additional advantages inherent in this technique are accelerated development due to impingement and a high degree of solution agitation, and increased wash efficiency through greater wash-water penetration of residual surface solutions.

In addition to use of an air/liquid bearing film-transport system, the EH-49 processor continuously and automatically varies the development of each portion of the film being processed to yield maximum image information.

The basic concepts of the air/liquid bearing film-transport system have been proved in the HTA-5 and its forerunners, but [redacted] STAT acknowledges that further research and development is necessary to realize the full potential of this advanced technique. Therefore, a substantial portion of the proposed program will be devoted to refining the transport system. Areas of investigation will include bearing geometry, vacuum capstan design and orientation, pneumodynamics of the air medium, and hydrodynamics of the solution medium.

The application of controlled development by the heat-shock method was pioneered by [redacted] STAT and will also be investigated during the program as an important design goal.

A third important area to be resolved is contaminant control, both inside and outside of the processor. Operation of the HTA-5 within the carefully controlled and instrumented environment provided by the GFE cleanroom will provide valuable data concerning the effect of a clean atmosphere on processing quality and, conversely, the effect of a large, chemically based machine on its environment. Advanced air and solution filtration will be incorporated in the HTA-5 system to complement the clean-room considerations.

1.5 COMPANY QUALIFICATIONS

STAT [redacted] is well known to the procuring activity as a highly qualified producer of standard and special-purpose film processors and as a successful research and development company in the photographic and electronic sciences. This proposal will not deal at length, therefore, with the adequate facilities and specialized personnel available to the proposed program. Rather, this contractor's qualifications to perform are based on lengthy experience and its successes with the unique problem of controlled development and frictionless film transport.

The proposed program is presented as one most likely to yield data and techniques on which to base the design of a processor whose operational and production performance will greatly exceed that of any processor now in existence. It is the opinion of [redacted] that the use of company-designed air/liquid transport and controllable-development techniques, plus its unique combination of engineering experience in reliability, cleanroom techniques, electronic controls, process chemistry, and materials and structures, is the surest way to acquire the knowledge necessary for the development and production of such a processor.

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SECTION 2

LABORATORY DESCRIPTION

[redacted] proposes the establishment of a research and development laboratory for the purpose of advancing the art and technology of film processing in general and the air/liquid bearing concept of film processing in particular.

The area selected for this purpose is a separate building on the north-east corner of the [redacted] plant, bounded by [redacted] and adjacent to the loading entries from these avenues. This area has been selected as suitable for both the installation of a GFE cleanroom and its supporting laboratories. This building has a separate entrance from [redacted] and is isolated from the production shops. It will, therefore, meet any necessary security requirement with a minimum of difficulty.

The layout of the proposed research and development facility is shown in Figure 2-1. The cleanroom will occupy an area of approximately 1200 square feet, and will be divided into three main areas. An area of approximately 28 by 26 feet will be used for installation of the HTA-5 processor on a GFE basis as a test vehicle. The other two areas will house a photographic evaluation laboratory and a sensitometric exposure laboratory, each of which will be provided with a light lock and will be accessible from the main test area as shown in the plan.

No → 1800 ft

Three light locks

It is proposed that the cleanroom be of the prefabricated portable type, consisting of stainless-steel panels supported by standard channel sections. The rooms will be provided with filtered, temperature-controlled, and humidity-controlled air. Access to the cleanrooms will be through an air shower and air locks equipped with suitable "clean tread" mats.

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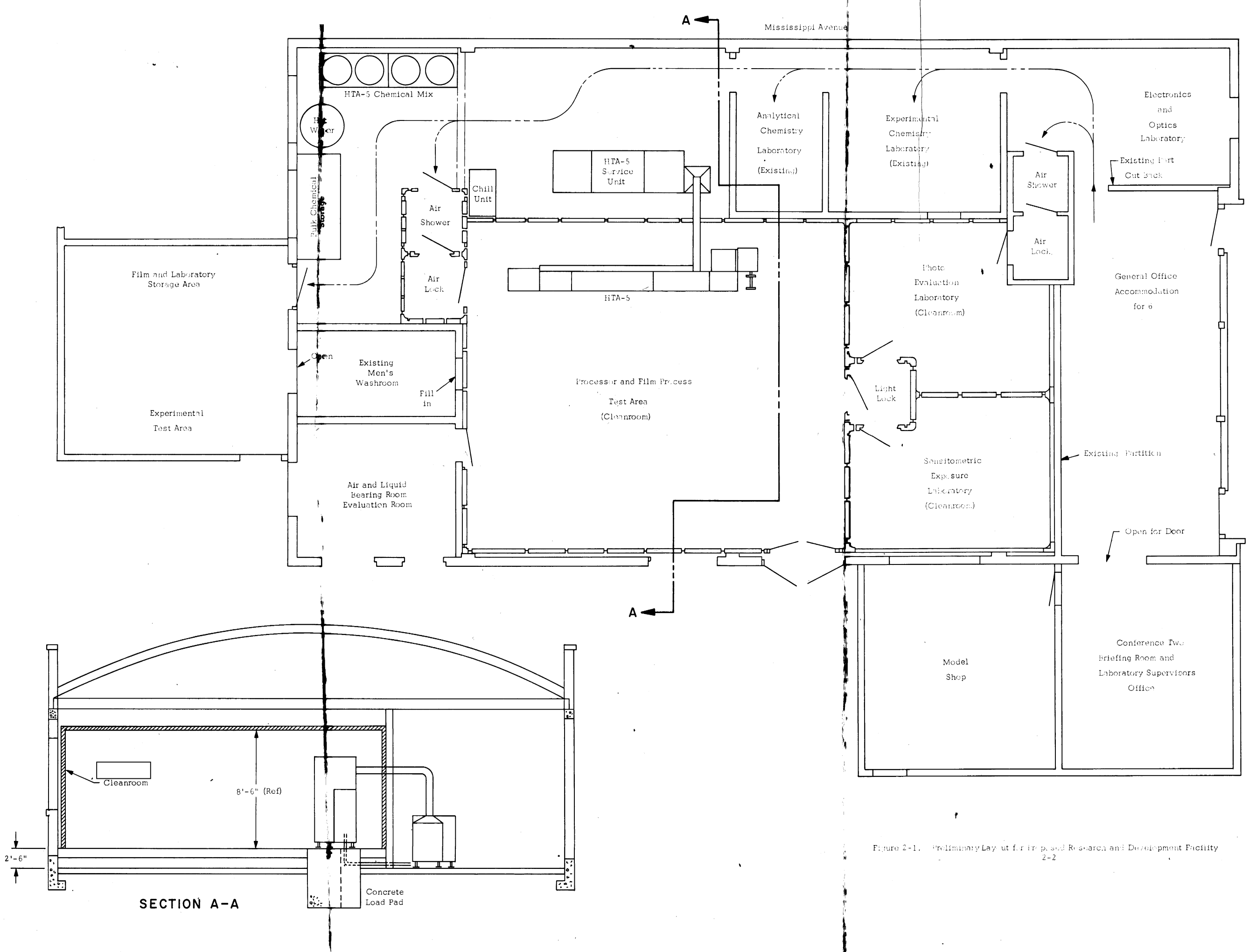

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Figure 2-1. Preliminary Layout for Proposed Research and Development Facility

It is recommended that the cleanroom be procured from [redacted] because of their extensive experience in specialized installations of this type, and that they should also be responsible for its installation in the area provided.

2.1 AIR- AND LIQUID-BEARING TEST LABORATORY

To study the design, performance, and efficiency of air and liquid bearings and air squeegees, an air- and liquid-bearing test laboratory is essential. Such an area will be provided adjacent to and with access from the cleanroom area (Figure 2-1) and will contain an air/liquid bearing test stand. The test stand will conform to the general configurations shown in Figures 2-2 and 2-3.

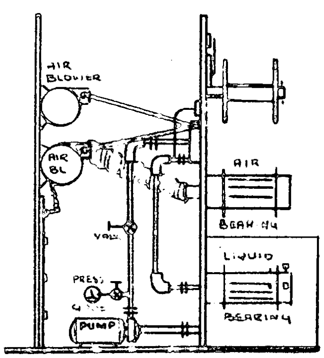
2.2 ELECTRONICS AND OPTICS LABORATORY

Since it is not proposed to limit the work conducted in this facility, an electronic and optics laboratory will be provided for research into controllable-development methods, density measurement, image-quality evaluation, and other important techniques.

2.3 ANALYTICAL AND EXPERIMENTAL CHEMISTRY LABORATORIES

To advance the design and efficiency of processing machinery, constant research into the properties of the chemical solutions is required. This research will furnish the design engineers with data pertinent to the functions and physical size of the machine. To support this aspect of process design, it is proposed to incorporate this company's existing chemistry laboratories in the facility.

To support the research areas described above, suitable storage areas and office accommodation will be provided as shown in the layout.



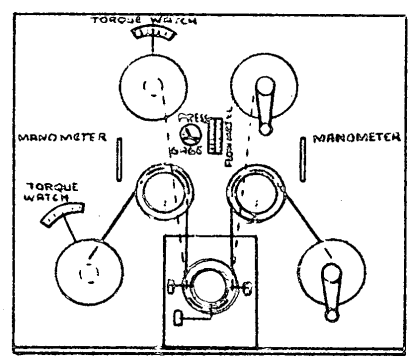


Figure 2-2. Air- and Liquid-Bearing Test Stand

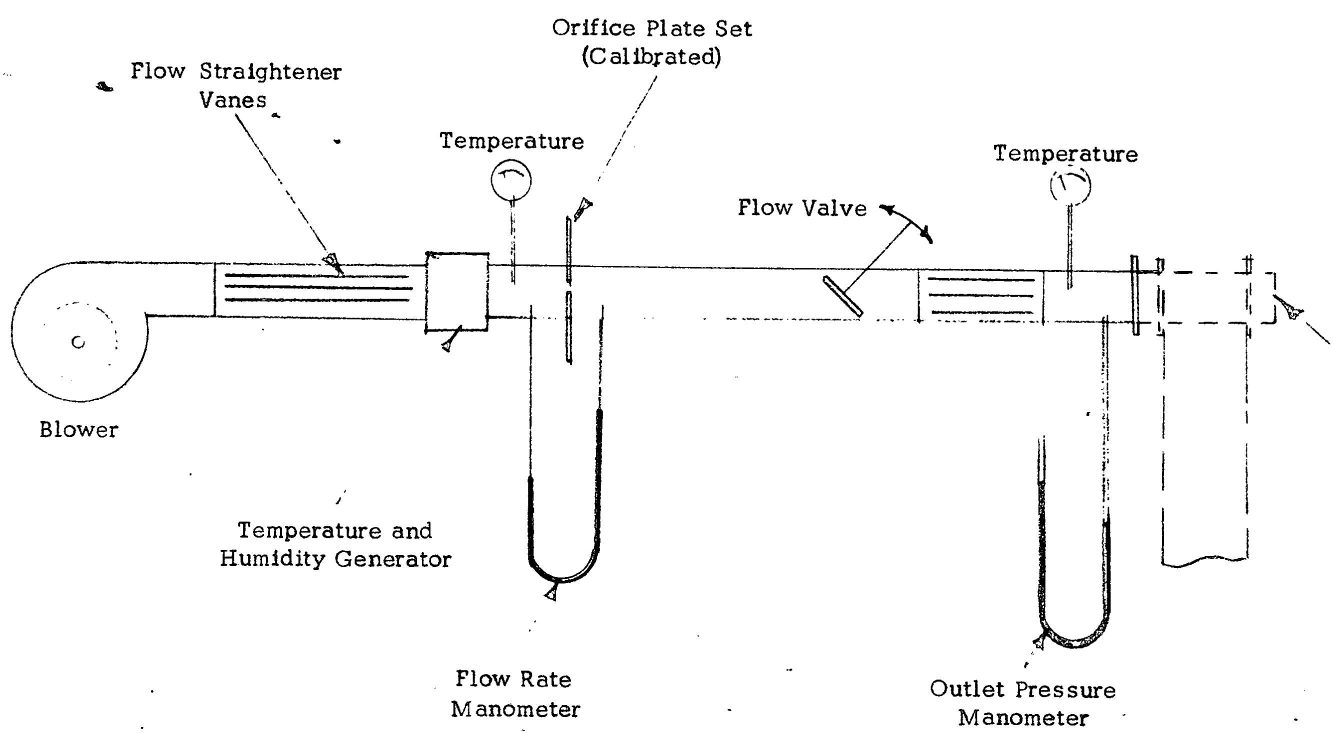


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Figure 2-3. Air Test Stand

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In summary, it can be seen from the proposed layout that [redacted] intends to provide a modern, well-equipped research and development center capable of undertaking research into all aspects of film processing to advance film-processing methods and the efficiency of the equipment.

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2 March 1964

DEVELOPMENT OBJECTIVES

PROCESSOR DEVELOPMENT PROGRAM

1. SCOPE. The development objectives covered herein set forth requirements for an investigative effort relating to photographic processing equipment and techniques. The program shall make use of the present HTA/5 processor on a GFE basis as a test vehicle, for specific investigative efforts in a GFE portable clean-room environment, adequately equipped and staffed to achieve conceptual and engineering advances in the art and technology of photographic film processing.

2. INVESTIGATIVE OBJECTIVES. The investigative objectives described below are primarily directed toward improvements in the liquid-air bearing concept because of its demonstrated significant advances in the state-of-the-art of film processing. It is not intended that these objectives restrict related efforts in other processing concepts that may be conceived as a result of this work; however, any major deviation from the objectives as set forth shall be approved by the project monitor.

3. DETAILED OBJECTIVES.

3.1. Liquid and Air Bearings. The major requirement for liquid bearings and air bearings is that they should provide stable cushions for the support of film webs "in-solution", as the film passes through the solution tanks, and "in-air" as the film web crosses over from one solution to the next. To improve these functions, the following investigations should be conducted:

3.1.1. Investigate new designs, configurations and concepts for liquid and air bearings respectively, with the objective of achieving the optimal film support and tracking with the minimum of respective solution and air flow.

3.1.2. With the object of increasing the mechanical efficiency of liquid and air bearings, investigate the effect of variable slot openings as well as liquid and air feed arrangements.

3.1.3. Measure energy levels required to maintain firm cushions over a wide range of load conditions encountered by change of film width from 70mm to 9½ inches and film thicknesses varying from 1.5 mils to 7.0 mils.

3.1.4. Establish the effect on film stability of increases or decreases in the diameter of liquid and air bearings.

3.1.5. Investigate the correlation between velocity and flow rate of solutions and air with the view of optimizing the values for each.

3.2. Air Squeegee. Investigate configurations and other parameters by which the efficiency of the air squeegee can be improved, with the minimum of air flow and/or power consumption.

3.3. Vacuum Capstans. Investigate designs for improving the vacuum capstan drive method for all applications and conditions, including:

3.3.1. Vacuum level versus volume.

3.3.2. Capstan diameters and configurations for variable film loads.

3.3.3. Determine under what conditions other materials, such as scintered metal, or teflon coatings, may be used and at what energy levels.

3.3.4. Effects of capstan configurations on tracking characteristics.

3.4. Plumbing. The requirements for large amounts of plumbing is inherent in processing equipment and contributes significantly to power losses. Effort should be expended to minimize these losses.

3.4.1. Determine which materials and fitting designs provide the least pressure drop and give the best non-leak performance.

3.4.2. Determine which pumps and seals provide the greatest efficiency with the least temperature rise of solution.

3.4.3. Investigate means of shortening the plumbing and air lines by placing service units in close proximity to the processor needs.

3.5. Solution Filtration. Filtration of solutions is required to remove large particles from solution that may cause film emulsion or base damage. This requirement has varied widely in new equipment over the years, from 0.3 micron to 20 micron particle size, with little scientific basis for the judgment.

3.5.1. Investigate the effects on film surfaces, by the liquid-air concept, with filtering at different particle size levels to establish a scientific basis for the selection of filters for solution and water.

3.6. Equipment Size.

3.6.1. Reevaluate the configuration and space required for each machine component to assure maximum utilization of machine space. Smaller bearing design may offer considerable opportunity for size reduction.

3.7. Power Consumption.

3.7.1. Reevaluate each electrically operated component to assure maximum electrical efficiency. Improvement of efficiency in liquid and air bearings and the air squeegee should greatly reduce the power required for pumping liquid and air.

3.8. Modular Design. Modular design and construction of processing equipment is of utmost importance to assure ready disassembly and reassembly for maximum portability, quicker maintenance by ready replacement of modules, less down time by ease of part replacement, and greater reliability.

3.8.1. Study modular concept with a view to:

3.8.1.1. Designing the processor in modules that are readily transportable for crating.

3.8.1.2. Keying the modules to assure proper reassembly with automatic module alignment.

3.8.1.3. Extending the modular concept to individual parts such as liquid bearings and air bearings. Intensive investigation should be directed to designing the bearings as self contained, self sufficient, electrically operated units. These should be easily removable and replaceable while the machine is operating. This may be accomplished by removable bearing cores to avoid collapse of the film strand during the interchange.

3.8.1.4. Use of multi-pin connectors for interconnecting modules.

3.9. Controllable Development Module. Controllable development has come to be recognized as a valuable asset in the processing of both original film and duplicates.

3.9.1. Investigate miniature designs of controllable development modules for insertion in the processor.

3.10. Density Measurement. Any controllable development system must include a precise method by which the densitometric characteristics of the film may be analyzed, in order to assure proper adjustment in subsequent localized processing.

3.10.1. Investigate densitometric analysis modules for use in conjunction with the controllable development module.

3.11. Splicing. Investigate new splicing methods and splicing apparatus for incorporation as an integrated module of the processor.

3.12. Reliability. One of the prime characteristics of a processor is its mechanical reliability and its ability to eliminate all possible damage to irreplaceable original film.

3.12.1. Evaluate the operational limitations of each operating component to assure absolute reliability.

3.12.2. Determine areas or functions that should have stand-by automatic switchover service units or components.

3.13. Threading. Investigate methods by which the liquid-air bearing processor may be simply threaded, preferably by automatic means.

3.14. Film Torque. An important element in modern processing is complete avoidance of any stress on the film web that may cause distortion or elongation of images by driving torque applied to the film web.

3.14.1. Devise techniques by which torque on the film web can be measured, controlled and minimized. Also establish some criteria by which the torque of the liquid-air bearing concept can be compared to that of presently standard techniques.

3.14.2. This investigation should include a measure of the torque required to draw film from the supply spool, with a view to driving the supply spool in proper synchronism with the processor drive capstan to avoid all possible stretching of the film.

3.15. Chemical Development. Investigate various chemical solutions, including viscous development with a view to reducing the space requirement without compromise of quality.

3.16. Chemical Fixation. Investigate machine chemical fixation to assure maximum efficiency within the space limitations. This should include concentrated, semi-viscous solutions.

3.17. Film Washing. Investigate film washing methods with a view to reducing the volume of wash water required, without sacrifice of archival quality.

3.18. Measure of Chemical Balance. Investigate electronic means by which the chemical balance can be continuously measured and recorded on dials attached to the side of the machine, or at the control panel.

3.19. Processor Control System. Investigate control functions for operation of the system, with a view to total centralization of required controls at the control panel.

3.20. Clean Room. Study the practical aspects of operating a processor in a clean-room atmosphere to establish parameters for a clean-room processor operation. This investigation should evaluate the effect of the room environment on the film during the processing cycle and should also evaluate the processor effect on the aerosol content of the clean-room when operated therein.

3.21. Drying Air. Investigate the particle size filtration required for drying air fed to a film drying cabinet.

3.22. Gamma Requirements. Investigate film gamma requirements as related to processing characteristics of the liquid-air bearing principle.

4. REPORTS. The contractor shall be required to submit monthly progress reports and periodic technical reports.

4.1. Monthly Reports. The monthly report shall be a letter type describing briefly the activities of the previous month and proposed work for the next month. This report shall include a monthly accounting of funds expended with an appropriate breakdown and documentation of verbal agreement made with the monitor.

4.2. Technical Reports. Technical reports shall be submitted on completion of each respective Research Objective, or at some significant point towards its accomplishment. These reports should describe the work performed with results, conclusions and recommendations.

5. ORGANIZATION. In order to assure development of a research environment conducive to the origination, development and testing of new concepts and techniques, the research group assigned to this program shall be organizationally separated from production personnel.

5.1. Personnel. Personnel chosen by the contractor to perform the research described herein shall be approved by the contract monitor.

5.1.1. Personnel assigned to this research program shall be assigned on a full-time basis.

6. CLEAN ROOM. The GFE clean-room will be provided and installed at the expense of the Government. Purchase of the clean-room and supervision of its installation shall be by the contractor. Installation shall be at some location within the contractor's plant acceptable to the contract monitor.

7. HTA/5. The GFE HTA/5 processor shall be installed in the GFE clean-room and brought to a suitable and reliable condition to properly serve as a test vehicle in any reasonable manner to accomplish the investigative objectives covered herein.

Uncl. 8. SECURITY. The enclosure utilized for this investigative program shall be closed to all personnel except those assigned who have proper security clearances and who have a need-to-know of work conducted therein.

Agency association Confidential.

SECTION 3

PROGRAM PLAN AND PERSONNEL

3.1 RESEARCH REQUIREMENTS

The first research undertaken in the facility will be to obtain film-drag coefficients. These are required to obtain the basic data on which the air- and liquid-bearing design criteria will be based. (Refer to Appendix 1.)

3.2 FILM-DRAG COEFFICIENT RESEARCH

The following program will be carried out:

1) Pressure/flow requirements for given speeds for air and liquid bearings will be determined.

2) Using the pressure/flow data, an investigation will be made to determine the effect of increases or decreases in the diameter of air and liquid bearings on film stability.

3) The effect of different slot and feed arrangements will be investigated with the objective of increasing the mechanical efficiency of air and liquid bearings.

4) The overall system efficiency will be investigated in terms of individually powered bearings versus a number of bearings fed from a common manifold using blowers or pumps of large horsepower.

6) Investigations to determine an efficient way to thread film automatically will be made.

3.3 PLUMBING RESEARCH

In conventional processors a minimum of plumbing is used, usually only that required for recirculation and drainage. In liquid-bearing processors, much plumbing is required. Investigations conducted by

STAT have shown the need for research to reduce pressure losses through plumbing fittings so that pump sizes can be reduced accordingly. The following investigations and tests will be conducted:

1) Standard plastic and stainless-steel fittings will be tested to find those through which the least pressure drop is developed and those giving the best nonleakage results. Tests will also be made on valves, disconnects, and filters.

2) Concurrently, extensive tests on as many types of pumps and seals as possible will be made to ascertain the best type for standard use. At the same time, temperature rises in solutions due to pumping action will be recorded.

3) The design of multiplenum pumps for increased pumping and maintenance efficiency will be investigated.

4) A hollow-wall tank configuration to obtain increased temperature-control efficiency and to eliminate bulky temperature-control equipment such as heat exchangers and a BTU input tank will be designed, built, and tested.

3.4 VACUUM CAPSTAN RESEARCH

An essential part of the [redacted] air/liquid bearing transport system is the vacuum capstan, an example of which is used in the HTA-5 processor. Further research is required to advance the development of vacuum capstans and will comprise the following: STAT

1) Tests will be carried out to ascertain which form of power source gives the widest possible application and the conditions for which it should be selected. The tests will cover high vacuum at low cfm and low vacuum at high cfm.

2) Tests to determine the best diameters and feed configurations for given loads will be conducted.

3) Investigations will be made to determine under what conditions, if any, a porous metal or plastic capstan could be used, and at what energy levels.

4) Tests will be conducted to establish the maintenance required on a porous metal capstan, if satisfactory in other respects.

5) An investigation of the possibility of a capstan design capable of operation from either a high or low positive or negative pressure with a high or low cfm energy source will be made, using data obtained from the tests and investigations described above.

6) Tests will be made on each type of standard film to determine the pressure level at which "dimpling" or permanent marking of the film occurs.

3.5 RELATED RESEARCH

Other essential areas of research include the following:

1) Investigation of design configurations for a rotating liquid-spray bearing which would also provide film support will extend the use of the liquid bearing concept into the spray processor area.

2) Some grounds exist for the belief that development can be accelerated by passing the film through a liquid bearing capable of supplying developer at a high pressure. It is proposed to examine the validity of this concept and to carry out tests sufficient to justify, if possible, further investigation.

3) The majority of air squeegees currently available operate on a high-pressure low-flow basis. [redacted] research has produced STAT a successful low-pressure high-volume air squeegee used on the HTA-5 processor. To design a similar air squeegee suitable for any given film width or thickness at a given film speed, additional research is needed to be able to plot curves giving the number and width of slots and the air

pressure and flow required. This research would also determine the gap between units necessary to reduce high-energy noise levels.

4) Photographic tests necessary to insure that designs selected are both photographically and mechanically sound should be conducted.

5) Preliminary work on the [redacted] air squeegee STAT described has shown that it is possible to dry film at low speeds. It will be necessary to plot drying curves under known relative humidity conditions, using both ambient and heated air, with a view toward increasing drier efficiency (or eliminating conventional driers entirely under certain conditions.)

3.6 DEVELOPMENTAL OBJECTIVES

Some of the areas of research and development necessary to increase the efficiency of processors designed for the air/liquid bearing concept, to decrease the total package size of the overall machine, to improve the design of modules for ready disassembly, reassembly, and maximum portability, and to provide easier maintenance through modular design of components, have been discussed. These represent the principal research objectives. As part of the developmental objectives, methods of obtaining automatic alignment of modules will also be investigated. *Important*

3.7 FUTURE RESEARCH AND DEVELOPMENT

1) Using the HTA-5 processor as a test vehicle, detailed research into the effects, on film development, of solids in chemical solutions and in air, will be conducted. This will be done by connecting various types and ratings of air and liquid filters to the HTA-5 processor and testing them in actual operation.

2) There are several theoretically possible methods of obtaining controllable development of film. Feasibility of various methods depends, to a great extent, on the length of film over which the control is required. In conjunction with a method of sensing film density at various stages of development or sensing the rate of development, intensive study and investigation is required to exploit the possibility of providing a packaged controllable-development module, using either hand control by the operator or automatic control by suitable electronic circuitry.

3.8 PERSONNEL

The facility will be staffed with personnel of the highest obtainable caliber, thoroughly experienced in the field of film processing or in related activities. The following staff is recommended.

1) Photographic Engineer
2) Chemical Engineer
3) Electromechanical Engineer
4) Electromechanical Technician
5) Photographic-Laboratory Technician.

The facility will be managed by a full-time supervisor who will be responsible for management under the direction of the [redacted] STAT

STAT [redacted] assistant director of engineering. A program organization chart is shown in Figure 3-1.

Additional services such as secretarial requirements, model shop labor, etc., will be obtained on an as-required basis. All assignments handled by the laboratory will channel through the laboratory director, who will check the initial requirement with the research coordinator to avoid duplication of effort within the company. A copy of the assignment together with the objectives of the investigation will be submitted to the project

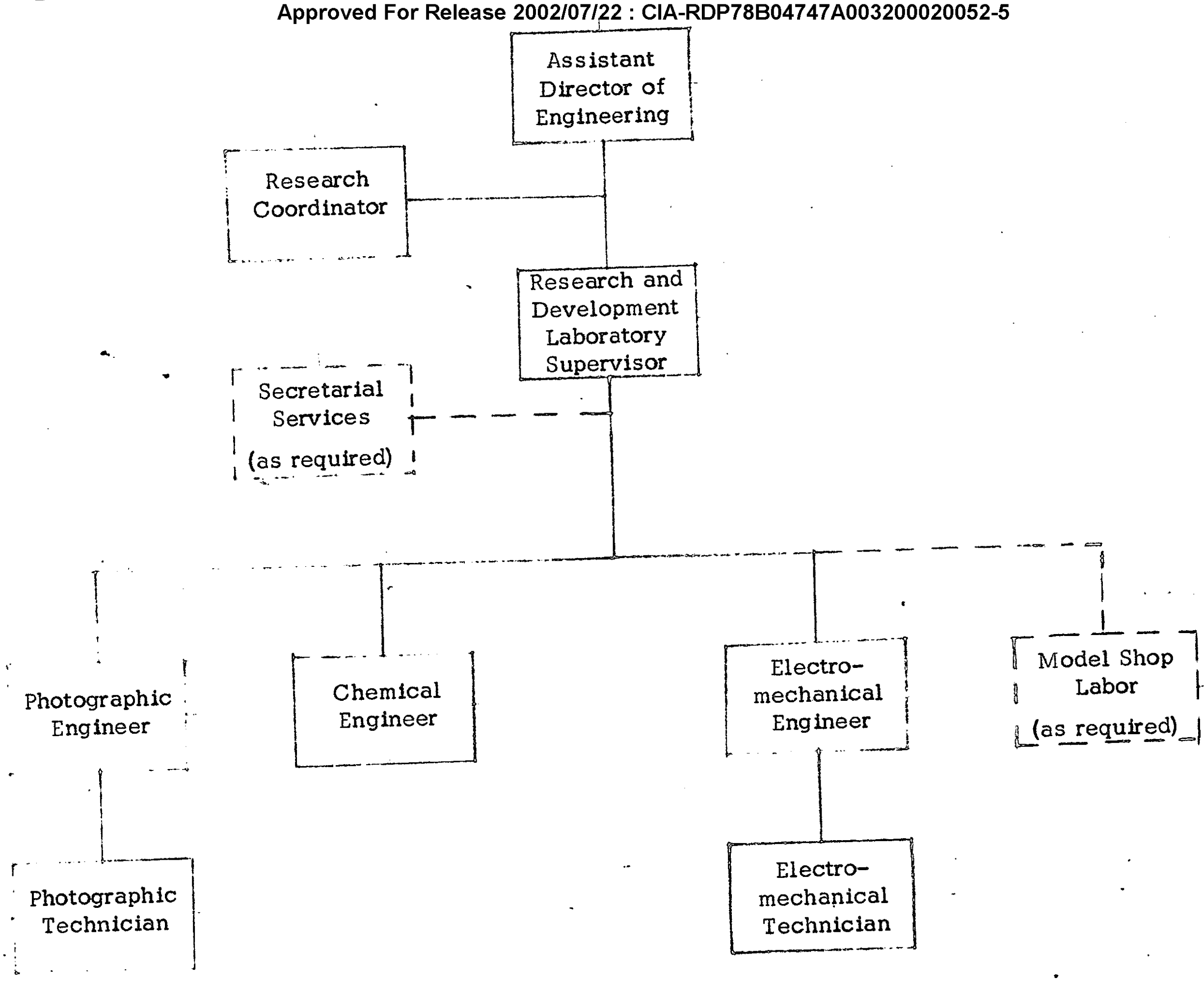

Figure 3-1. Program Organization

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monitor for approval prior to commencement of work. An assignment sheet will be drawn up describing the research or development work to be undertaken. A copy of this will be given to each person assigned, and he will record the time spent on each assignment.

A weekly report on each assignment will be required from all personnel. These will be filed in a master file established for each assignment. All man-hours, expenditures, reports, photographs, charts, and other relevant data for each assignment will be filed in the master file. On completion of an assignment, a final technical report including all plots, formulas, and recommendations will be prepared and issued to responsible authorities.

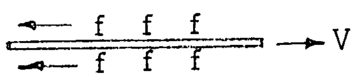
To promote the atmosphere essential to an organization of this nature, all assignments will be discussed with the personnel of the laboratory to encourage a free interchange of ideas and opinions and to insure identification of the staff with the projects undertaken. If essential outside assistance in specialized fields is needed, it will be procured on a consulting basis to insure maximum efficiency.

Probably some will be necessary

APPENDIX A

Notes on drag of film when pulled through water or near-water solutions:

When any body is moved through water at a velocity V there is a resisting force F exerted by the water on the body moving through it. In the case of film or thin flat plates of little or no frontal area, this force is known as skin friction.



This force may be calculated from the following equation:

$$F = C_F \frac{\rho A V^2}{2} \qquad (1)$$

where

F is the skin friction force in lbs, C_F is a dimensionless coefficient, ρ is the mass density of the liquid in slug/ft^3, A is the area in sq ft, and V is the velocity in ft/sec

Note ρ of water at 20°C is 1.937 slug/ft^3 or $1.937 \frac{\text{lbs f} \quad \text{sec}^2}{\text{ft}^4}$

The drag coefficient C_f is mainly proportional to the Reynolds number.

$$R.N. = \frac{VL}{\nu} \qquad (2)$$

where

V is velocity in lb/sec

L is length

v is kinematic viscosity

in ft^2/sec

v for water at 20°C is 1.08×10^{-5} (this number is very temperature-sensitive)

For smooth, flat, plates the coefficient C_F has been approximated as follows:

$1 \ \underline{L}\ RN\ \underline{L}\ 5 \times 10^5$

$$C_F = \frac{1.327}{\sqrt{R.N}} \qquad (3)$$

$5 \times 10^5\ \underline{L}\ R.N\ \underline{L}\ 5 \times 10^6$

$$C_F = \frac{0.074}{\sqrt[5]{R.N}} - \frac{1700}{R.N.} \qquad (4)$$

and for $RN > 5 \times 10^6$

$$C_F = \frac{0.455}{\left[\log_{10} (R.N.)\right]^{2.58}} \qquad (5)$$

However, it is not known how well these approximations apply to film in water, developer, and fix solutions.

There are several things to note carefully.

The entire area of the film - both sides included - that is in solution between drive points must be considered.

The drag varies according to the square of the velocity. Double the speed and get 4 times the drag.

In air-liquid bearing machines, the load on bearings is due almost completely to the fluid friction drag. Only that part of film tension due to tensioning devices is not caused by fluid friction. The tension is cumulative from tank to tank and is greatest near the tail end of the machine.

It is instructive to compute an example according to the formulas above to understand why the above discussion is pertinent and why additional research is needed.

The HTA-5 had 160 feet of 9-1/2-inch wide film submerged from head end to tail end. At 20 feet/min the drag force was, according to formula

$$F = C_F \frac{\rho A V^2}{2}$$

First compute R.N. to evaluate C_F

$$R.N. = \frac{VL}{v} = \frac{\frac{20}{60} \times 160}{1.08 \times 10^{-5}}$$

$$= \frac{0.33 \times 1.60}{1.08} \times 10^7 = 4.9 \times 10^6$$

since this is very close to 5×10^6 both (4) and (5) forms of C_ρ will be evaluated.

$$C_F = \frac{0.074}{\sqrt[5]{R.N.}} - \frac{1700}{R.N.} \qquad (4)$$

$$= \frac{0.074}{\sqrt[5]{49 \times 10}} - \frac{1700}{4.9 \times 10^6}$$

$$= \frac{0.074}{21.8} - \frac{1700}{4.9 \times 10^6}$$

$$3.4 \times 10^{-3} - 0.348 \times 10^{-3} = 3.05 \times 10^{-3}$$

or

$$C_F = \frac{0.455}{\left[\log_{10} (R.N)\right]^{2.58}} \qquad (5)$$

$$C_F = \frac{0.455}{\left[\log_{10} 4.9 \times 10^6\right]^{2.58}} = \frac{0.455}{\left[6.690\right]^{2.58}}$$

$$= \frac{0.455}{137} = \frac{4.55 \times 10^{-1}}{1.37 \times 10^{2}} = 3.31 \times 10^{-3}$$

We shall use the slightly larger (10 percent) value of 3.31 for computation of F.

$$F = \frac{3.31 \times 10^{-3} \times 1.937 \; (160 \times 0.79 \times 2) \times \left(\frac{20}{60}\right)^2}{2}$$

$$= \frac{3.31 \times 1.937 \times 2.53 \times 1.11}{2} \times 10^{-2}$$

$$= 9.0 \times 10^{-2} = .09 \text{ lbs.}$$

However, in the HTA-5, drags of almost 2 pounds were experienced. Some of this was the accumulator tension and some of this was higher fluid friction than the equation predicts, thus pointing up the need for experimental work to get the C_F for film instead of smooth flat plates.