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A. Contractor shall furnish the necessary services, facilities and materials to accomplish the work set forth herein below and make delivery thereof to the Government:

WORK STATEMENT

TASK I - FILM HANDLING FEASIBILITY STUDY

Itek will analyze the inherent problem in producing a high speed film transport system which has the capability of maintaining film velocities to level of accuracy consistent with the requirements of a high resolution (minimum of 100 l/mm on film) panoramic camera system for use in photography from orbiting satellites which may operate in a V/H range from 0.06 rad/sec to 0.035 rad/sec.

At least two of the more feasible approaches will be designed and manufactured in the form of engineering (non-flight) models. These models will be of a sufficient degree of sophistication to allow complete evaluation of film drive problems and will permit a determination to be made of their feasibility when incorporated as part of the complete camera. Both models will incorporate the necessary film drum rotation and translation mechanizations for compensation of all image motion vectors along a line in the format and over a 120-degree scan angle.

Two basic methods of film transport will be investigated. The first will be a method which allows exposure of the film frame after frame but necessitates storage of film loops to account for the periods during which no exposure is being made. The second method will be that in which the film is moved passed the exposing slit continuously at a constant velocity with the slit capped when exposure is not desired. This method requires a means of coding or indexing the films such that an accurate accounting of the positions of the unexposed areas can be maintained in order that these areas can be exposed at a later time. A careful study will be made of the reliability and practicability of the film reversing operation. Careful attention will be given to minimizing film wastage and the trade-off between start-up power and minimum time for an on-off cycle.

In the case of the accelerated film approach, an evaluation of wasted film due to degraded imagery should be made. Also the feasibility of using an interrupted scan mode of operation should be studied. The problem of additional programmer complexity should also be examined in this context.

The models will be operated in a vacuum chamber to ascertain the dynamic effects of the absence of air. No further environmental testing will be undertaken in conjunction with this effort. Vacuum tests will be conducted using existing facilities which are currently being utilized on other Government contracts. This effort is predicated upon the use of these facilities on a non-interference basis.

All design, testing and evaluation shall conform to good commercial practice rather than to military specifications.

At the conclusion of the six month program, a detailed evaluation report on each of the two prototypes will be delivered. This report will include the following:

a. The results of experiments designed to measure the film velocity errors with description of measuring techniques.

b. A statistical estimate of image degradation due to film velocity error.

c. The results of environment chamber tests designed to examine high speed film handling problems (such as corona discharge) at operational gas pressures and film dynamics, To include the results of that portion of this task undertaken by Itek's subcontractor, Ion Physics Corporation (a subsidiary of High Voltage Engr. Corp), said sub-task to be performed in accordance with the <u>Task Statement</u>

Corona Discharge Analysis as enumerated in Contractor's Addendum #3 of proposal 9204-SHF64-69, subject Task Statement herein incorporated by reference.

d. The results of experiments with Kodak Type 4404 7" film designed to test the two prototypes for film damage (scratching, etc.)

e. A summary comparison of the two prototypes including operational considerations and estimated reliability.

TASK II - CAMERA DYNAMICS STUDIES

Task II is comprised of the following individual sub-tasks:

a. Dynamic Analysis

b. Camera Bearing Development

c. Evaluation and Reports

A. Dynamics Analysis

Analytical studies shall be made of camera dynamics in order to provide a basis for camera and spacecraft design and integration; specific items requiring study include:

(1) Critical system bearing loads during in-flight operation and pre-launch testing.

(2) The effect of rolling element bearing noise (in both the main bearing and film transport) on camera system vibration.

(3) The effect of spacecraft torquing on camera rotational rate and bearing loads.

(4) The effect of camera component (i.e: film supply and take-up spools, intermittent film drive roller, etc.) acceleration on camera rotational rate and bearing loads.

(5) The effect of shifts in film center of gravity on camera bearing loads and spacecraft attitude control.

(6) The integrated effect on image quality resulting from camera dynamics which shall include spacecraft motions directly related

inertial effects of the motion of the camera system and its components, but shall not include the effects of film transport errors.

B. Camera Bearing Development

A detailed design study and test program shall be conducted to develop the camera's main optical bar bearing. Two alternative approaches shall be considered: one, a gas-lubricated bearing and two, a rolling-element bearing. The design of each of these alternatives shall be suitable for in-flight operation, pre-launch (vertical attitude) testing and in-plant (horizontal attitude) testing when utilized with a small diameter rolling element outboard bearing and slip rings for electrically coupling the optical bar to the spacecraft. A complete full-scale single camera mock-up of each alternative shall be designed and fabricated for evaluation testing under operational environmental conditions. In order to permit realistic evaluation of operational conditions (i.e: steady-state, start-up and stop, and caged modes of operation in a near-vacuum environment), the weight and center of gravity of each mock-up shall be as accurate as the effort under Task V permits.

The design of each main bearing alternative shall be in accordance with the loads established in section A of this task. Design of the gas bearing shall be based upon a survey of large air bearings designed for operation under near-vacuum environmental conditions; particular emphasis shall be directed toward the development of a highly reliable bearing requiring a minimum gas flow rate. Included in this effort shall be the investigation of the design of a bearing caging system and a suitable air supply and metering system.

In addition to the functional testing of the two alternative main bearing designs, each shall be instrumented and tested for vibrational effects which could cause image degradation.

C. Evaluation and Reports

Upon conclusion of the task defined above, the following reports shall be prepared.

(1) A report summarizing the results of dynamics analysis studies included in section A.

(2) Upon completion of the design study and test program for the two alternative main bearings, test results shall be evaluated and summarized in a report which shall include:

(a) Bearing design study summary

(b) Test program results and conclusions

(c) Application of test results to free fall conditions and launch load conditions

(d) Preliminary design specification for the immediate detail engineering design of the (preferred) main and outboard bearing system and slip ring assembly.

A study program for this project will enable us to carefully analyze the system requirements from an optical, mechanical, thermal and structural viewpoint, and verify our judgement in solving some anticipated problems in component fabrication, testing and use.

A. OPTICAL DESIGN

A six-month effort is planned for completion of a final optical design for the proposed system. The optical system to be designed shall be a 60-inch focal length, f/3 system, 6-inch field, capable of providing the best possible image quality on 4404 film with a minus blue filter. The type of lens considered shall be a meniscus corrected catadioptric, preferably with no aspheric surfaces. The overall length and other optical characteristics shall be suitable for the intended application.

An optical design will be carried out using our 924 computer. The length constraints of the system will require modification of existing programs. The mechanical and thermal tolerances will be programmed and analysed and system analysis will be done to evaluate the effect of environment upon the optical system.

As a backup factor, a lens design will be procured from an independent source which will be evaluated along with the Itek design. This will be carried only to a stage sufficient to determine feasibility and image quality.

A lens design and preliminary tolerancing analysis will be presented at the end ... ry design will be satisfactory for prototype fabrication of elements.

A final report will be supplied at the end of the sixth month covering all design and analysis carried out. The final design shall incorporate all features appropriate to production quantities.

Continuous system analysis and consulting services will be supplied to the project and to the optical manufacturing department.

B. CRITICAL COMPONENTS

Our assessment of the preliminary design layout reveals no basic optical fabrication problems which lie beyond moderate extensions of our present knowledge of the state of the art. There are, however, several expected problem areas in the larger components for which some experimental verification of our design judgement is recommended. The engineering of the structure of the elements, and their proper support both during fabrication and in use is, as in most engineering, subject to only imperfect quantitative analysis. The anticipated restriction on weight will not permit "over-design", and we need to assure ourselves, when we have designed to an acceptable weight by increasing the complexity of the structures or reducing their stiffness, that we have not trespassed beyond the limits of our ingenuity in fabricating, testing and mounting these items for use. Single unit trial fabrication of the three largest components and their mounts is proposed in order to verify that our design is adequate in the areas discussed below:

1. CORRECTOR LENS

The structural configuration is totally determined by the optical

(a) Fabrication Problems

No major problems are anticipated, but proper support in fabrication and adequate testing (particularly if an aspheric surface is included) will require careful engineering.

(b) Support Problems

Our past success in using locating shoulders of cast-in-place epoxy for mounting large lens elements indicates that we can readily retain optical performance in any reasonable acceleration environment. Studies of the optical effects, in flat windows, of radial (center to edge) temperature gradients indicate that intolerable defocussing and zonal aberrations may be generated in space environments unless substantial edge insulation is used.

Without such insulation, one can expect that the balancing of heat fluxes through the faces and edge will dictate that the temperature at the center of a window differs from the temperature at the edge. If the center is warmer than the edge, the center thickness of the window and the index of refraction of the glass at the center are both increased as compared to the edge. The window thus becomes, in effect, a lens and may cause both a shift in the final image plane and zonal aberations in the final wave front. This problem was discussed on page 19 of SHF64-52 of the 9096/3233 presentation material.

Extension of the calculation techniques to the nearly concentric spherical shell of this lens, modification of cast-in-place epoxy techniques to the use of foamed-in-place urethanes, and verification of their utility for the projected thermal environment should be undertaken, and results verified by trial.

2. FOLDING MIRROR*

We anticipate that material selection and configuration will be dictated by the thermal environment. A substantial difference in heat flux at those points nearest to and furthest from the corrector lens aperture, caused by the variation in the total angular field of diffusely reflected sunlight (albedo) seen by these elements through the corrector, can be expected. This variation in heat input leads to the generation of temperature differences throughout the element, and the consequent non-uniform thermal expansion can cause bending and warping of the element. Noting that we are concerned with surface deflections measured in microinches, and that thermal expansion coefficients are of the order of 10^{-5} to 10^{-6} per degree centigrade, it is apparent that we must take into consideration temperature differences of the order of 1°C. An increase in

* Refer to page 20 thru 24, Section SHF-52 of 9096/3233 presentation material.

thermal conductivity decreases the temperature differences which may develop, while a reduction of thermal expansion coefficient reduces the deformations induced. The proper combined figure of merit for material selection is k/x, the ratio of thermal conductivity k to thermal expansion coefficient x . Values of

Fused Silica	2.6 (10^6) BTU/HR-FT
Aluminum	9.6 (10^6)
Beryllium	13.3 (10^6)

These numbers, and our previous experience, indicate that we will most likely choose beryllium for this mirror.

Our present best techniques for metal mirrors require electroless nickel plating. The bi-metal effect with this coating, and the unusual central perforation (rectangular, with the axis of the perforation at 45° from the surface) are expected to perturb the working of the mirror.

(a) Fabrication Problems

Pressing, machining and stabilization by heat treatment of the mirror blank appear straight forward. Some difficulty in polishing a 30 inch diameter blank with a straight through rectangular perforation (2" x 6", possibly as large as 4" x 10") might be anticipated. Present techniques require that, during polishing, this perforation be almost completed filled (a gap of 1/8" can be readily tolerated) with the same material as the bulk of the mirror. This avoids producing a turned down edge which usually develops if large internal surface discontinuities are left. The polishing lap usually prefers to "see" a continuous surface. Some success is had occasionally without filler pieces in small circular central perforations, but the possible size and rectangular shape of this perforation are expected to require some variations in the art of polishing. With this perforation centered at 45°, an acute angular edge is formed on one side, and securing a good optical figure near the apex of this edge may be very difficult, and a different configuration necessary.

Much evidence indicates that substantial stresses exist in a Kanigen electroless nickel coating on a beryllium substrate at room temperature. One may postulate a stress free coating at the plating temperature (180 - 200°F), or stress relief at the heat treatment temperature (375°F) used to harden the coating. The first postulate, may be used to calculate a 5 wave perturbation of figure on a 26 inch diameter, and one inch thick mirror when .002 inches of the coating is removed by polishing. If other requirements permit use of a thin mirror, our judgement of the compromise between weight and this perturbation should receive at least a preliminary test in fabrication before the study phase can be considered sufficiently complete.

(b) Support Problems

We have had some success in elastomeric mounting of comparable metal mirrors and the suitability of this method will be considered in the light of the expected operational environment. While the elastomeric method of supporting the beryllium mirror appears to be the best approach at this time, we have experienced a few unusual problems in the past with a 28 inch diameter circular mirror mounted in this manner. The mirror we propose is somewhat thicker than the 28 inch mirror, but is non-circular. In addition, rather than being located outside the optical system, as was the 28 inch mirror, it is within where its position is critical to aberation correction and focus. Because of the differences between our past experience and our present problem we plan to make and test the elastomeric method of mounting to determine its suitability for this application.

3. PRIMARY MIRROR

The primary mirror is sufficiently removed from the entrance aperture that albedo and other heat fluxes do not require metal construction, and advantage may be taken of the low thermal expansion coefficient of fused silica to minimize the effects of slow temperature drifts. Weight considerations recommend the eggcrate ribbed structure, but it remains to be verified that the heat fluxes are sufficiently small to allow this further reduction in effective thermal conductivity.

(a) Fabrication Problems

With proper rib design, i.e. maintaining a ratio of rib spacing to plate thickness of 4:1 or less, no fabrication difficulties are anticipated. The absence of a central perforation also eases the difficulty of fabrication of this mirror. Our experience with egg-crate mirrors indicates that good uniform back support is necessary during polishing.

(b) Support Problems

Careful engineering of the support configuration is expected to yield success as designed. The probable ribbed structure is not, however, amenable to very precise stress and thermal analysis, and verification of the adequacy of structure and support configuration should be sought experimentally. Some crude experiments on the change in figure of a comparable eggcrate mirror in vertical and in horizontal positions showed a two wavelength change in the optical figure of the surface. It is thus apparent that this support problem cannot be ignored, but we expect proper support design to reduce the possible distortion to a tolerable level.

C. OTHER THERMAL ASPECTS

In addition to seeking verification, by trial fabrication, of the solutions to the problems outlined above, the design study will also include a consideration of the following:

a. Calculation of the defocussing and aberration effects of uniform temperature excursions of the various elements, both individually and collectively.

b. Consideration of the heat fluxes at the small corrector lens group. A portion of the cell supporting this group may be asymmetrically subjected to albedo heat flux. The necessity for using a cell of high thermal conductivity and insulating the elements from the cell must be studied, both for reduction of asymmetric temperature gradients within the elements and reduction of cell thermal deformations which may tilt and decenter the elements.

c. An overall thermal analysis, to define the expected heat fluxes, and the temperature-time history of all elements and structural components in the thermal environment which may be estimated from definition of the mission of the system.

D. Conclusion

The proposed program will provide a well thought out design, and initial experimental verification that our solutions approach minimum weight without requiring major improvements in the state of art of component fabrication. This experimental verification appears very desirable before embarking on a more extensive program of prototype qualification and eventual production. It can be undertaken using the results of the preliminary optical design, need not wait for optical design optimization, and thus does not alter the total elapsed time for the study program. It should also assist materially in reducing the elapsed time and cost of prototype qualification, and allow more precise planning of the qualification, and production phases for this system.

TASK IV - FACILITIES STUDY

The purpose of this task will be to survey Phase II facility requirements for environmental test, project, optical fabrication, assembly, field service, and mission support. Particular attention will be paid to requirements for leasehold improvements and government furnished equipment. Long lead items which might delay scheduled delivery of operational equipment will be identified to the contracting agency as soon as they are evident.

Specifications for facilities and equipment will be prepared in detail. Schedules and costs of facility construction and furnishings, including all pertinent data, will be developed and presented in a summary document at the end of the five month period.

TASK V - DESIGN AND ENGINEERING

Task V is comprised of the following individual efforts:

A. Task I and II Mockup Support

B. Interface Definitization

C. Structural Design

D. Panoramic Geometry Method

E. Pressurization Design

F. Weight, Balance and Momentum Accounting

G. Camera System Mockup

A. Task I and II Mockup Support

Provide coordination such that the brassboard designs for the film transport and bearing system are compatible to the extent that no major redesign will be necessary when they are mated in the final configuration.

B. Interface Definitization

Study power requirements, vehicle loading, window sizes and placements, electrical cable requirements, and all other items necessary to the definition of vehicle requirements.

C. Structural Design

Analyze pertinent parameters such as interoptic tolerance, expected thermal variation, launch loads and ground test requirements. Design appropriate camera structure and camera-to-vehicle mount to the detail which allows definition of required materials and allowable dimensional tolerances. Also included will be a continuous accounting of the system weight and balance. The production of detailed drawings and component specifications will not be part of this effort.

D. Panoramic Geometry Method

Consideration will be given to providing a fiducial system such that a definite relationship can be established between image points and the original object points.

E. Pressurization Design

Consider the parameters affecting the maintenance of a pressure at the film transport area such that corona discharge is obviated. The amount of spillage of air from the camera air bearing will be accounted for and calculations made for makeup air if needed.

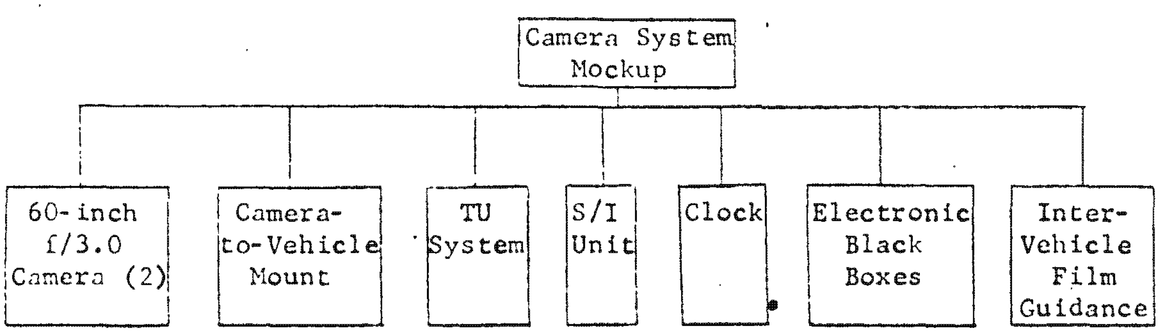
F. Weight, Balance and Momentum Accounting

Maintain a continual accounting in a detailed way of the noted items such that the contracting agency can maintain an accurate satellite reconnaisance system weight and balance budget.

G. Camera System Mockup

Construction of wood and metal mockups showing proper size and space relationships of all camera system components, their relationship to each other, and to the vehicle.

The following figure is a block diagram of the camera system mockup:



TASK VI - PROGRAM ANALYSIS

Continue analysis of the Phase II program with regard to schedules and lead times. This effort will result in a definitive schedule for Phase II at the completion of Phase I. During Phase I, long lead items affecting Phase II will be identified as they emerge.

B. DELIVERY

Contractor shall deliver the data, services and equipment called for herein above in accordance with the following schedule:

Item	Quantity	Description	Delivery Date
1	1	Engineering model of a constant velocity film transport system	12/31/64
2	1	Engineering model of an intermittent film transport system	12/31/64
3	1	Evaluation report of the performance of the two models (Items 1 and 2 above)	12/31/64
4	1	Full scale single camera dynamic mockup incorporating the main gas bearing	12/31/64
5	1	Full scale single camera dynamic mockup incorporating rolling element main bearings	12/31/64
6	1	Evaluation report of the performance of the bearings incorporated in the two models (Items 4 and 5 above)	12/31/64
7	1	Detailed report of the camera dynamics analytical studies	12/31/64
8	1	Lens design and preliminary tolerancing analysis	9/30/64
9	1	Final report covering all optical design & analysis carried out	12/31/64
10	-	Fabricated elements of the optical system including one each of the corrector plate, primary mirror, folding mirror and associated mounts	12/31/64

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Item	Quantity	Description	Delivery Date
11	1	Summary report of facility requirements, costs, schedules and specifications for their construction	11/30/64
12	1	Interface document defining camera system envelope, weights, power requirements, and other camera-spacecraft interface factors	8/31/64
13	1	Full scale design mockup of the complete camera system	12/31/64
14	1	Detailed report summarizing the complete camera system design	12/31/64
15	1	Program Plan for Phase II	12/31/64

C. CURRENT REIMBURSEMENT

The Contractor shall be entitled to current reimbursement of 100% of costs incurred in the performance of work called for hereunder up to 90% of the amount authorized for expenditures or obligation in Paragraph 6 of this Letter Contract. Invoices shall be authenticated by an officer of the Fiscal Office of the Contractor and be accompanied with appropriate statements of costs incurred. For purposes of billing current costs incurred under this contract, Contractor shall use those rates which are currently approved by the cognizant military department for billing purposes under CPFF contracts.

D. WAIVER OF REQUIREMENTS OF GENERAL PROVISIONS

Notwithstanding the requirements of any of the General Provisions of this contract to the contrary, whensoever the Contractor, in performance of the work under this contract, shall find that the requirements of any of the clauses of the General Provisions are in conflict with security instructions issued to the Contractor by the Contracting Officer or by his duly authorized representative for security matters, the Contractor shall call the attention of the Contracting Officer to such conflict and the Contracting Officer or his duly authorized representative for security matters shall (i) modify or rescind such security requirements, or (ii) the Contracting Officer shall issue to the Contractor a waiver of compliance with the requirements of the General Provisions conflicting with such security requirements. Any waiver of compliance with the General Provisions of this contract issued by the Contracting Officer shall be in writing, except that the approval by the Contracting Officer of any subcontract issued hereunder by the Contractor shall be deemed to constitute approval of waiver of any clauses of the General Provisions in conflict with the stipulations of such subcontract.

E. SPECIAL SECURITY RESTRICTIONS

The Contractor shall not reveal (i) the specific nature or any details of the work being performed hereunder or (ii) any information whatsoever with respect to the department of the Government sponsoring this contract and the work thereunder except as the Contractor is directed or permitted to reveal such information by the Contracting Officer or by his duly authorized representative for security matters, and notwithstanding any clause or section of this contract to the contrary, the Contractor shall not interpret any clause or section of this contract as requiring or permitting divulgence of such information to any person, public or private, or to any officer or department of the Government without the express consent of the Contracting Officer or his duly authorized representative for security matters.

F. ANTICIPATORY COSTS

All costs which have been incurred by the Contractor on or after 1 July 1964, in anticipation of and prior to the signing of this contract, and which, if incurred after the signing of this contract, would have been considered as items of allowable costs hereunder, will be accepted by the Contracting Officer as allowable costs under this contract.

G. FACILITIES

Contractor is authorized to use on a no-charge-for-use basis those facilities furnished or to be hereinafter furnished under Air Force facilities contract No. AF33(657)-8886, provided the use of such facilities does not interfere with the purpose for which such facilities are being furnished.

H. MONTHLY COST STATUS REPORT

Contractor shall submit a monthly report of expenditures and commitments incurred under the contract, together with an estimate of costs to complete the contract. If the total is different from the estimated cost, Contractor shall give reasons therefor. The detailed format and submission dates will be the subject of further negotiation between the parties.

H. Alternate Configuration Study

Additional study of some alternative camera configurations concentrated during the first month of the Phase I effort. The purpose of this effort is to confirm or have a basis for modification of the camera configuration chosen. This work may include preliminary weight and power estimates. Work will proceed in close coordination with the contracting agency. Specific reporting requirements will be worked out as necessary.