IMAGE VELOCITY SENSOR SUBSYSTEM

AD HOC REVIEW GROUP

FINAL REPORT

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I. INTRODUCTION

The Image Velocity Sensor problem has been a critical item since the beginning of the MOL Program because it is essential to the performance of the unmanned system and highly desirable for the manned version of MOL. At the time MOL was originally conceived, the image tracking function was to be a manual task and the automatic tracking, by means of a closed loop device such as an Image Velocity Sensor, was not yet considered technically practical. In the early phase of the MOL Program several schemes were proposed and, eventually, because of the criticality of this problem, three approaches, presented by Itek, Goodyear, and Hycon, were started.

In the spring of 1968 significant problems were uncovered when General Electric conducted some of the early simulations and tests on the breadboard models supplied by each of the three subcontractors. The problem of whether appropriate closed loop image tracking techniques could be perfected in time for the required integration into the system became a critical program concern. The program development schedule called for elimination of one of the three competing contractors and General Electric recommended the termination of the Itek contract. MOL program management, however, elected to continue with the three because the other subcontractors were also having difficulties and there were some questions concerning General Electric's test and evaluation techniques.

In view of the foregoing, it was decided to convene an IVS Ad Hoc Committee to review the MOL image tracking problem, to compare the proposed approaches and, if appropriate, to recommend alternate methods for accomplishing the image tracking task. Ideas such as laser ranging and open loop operations with the aid of precise celestial target referencing were proposed as alternate schemes.

While the Committee was being formed, General Electric and the subcontractors continued with their work and made significant progress toward eliminating some of the deficiencies discovered in earlier tests. The Committee convened on 20 September and after a review of the subcontractors' work and the General Electric evaluation process, it was the consensus of the Committee that the MOL Program can proceed with the selection of one of the proposed schemes and that it is probable that target tracking will be adequate to meet system requirements, and the introduction of alternative schemes would serve no useful purpose.

Some questions remain on the validity of the specifications, the fundamental understanding of the various schemes, the ultimate choice of subcontractor, the validity of the simulation, and the operation of the system in the presence of clouds. These subjects and the Committee's recommendations are discussed below.

II. SPECIFICATIONS

1. Status

a. General

The critical performance requirements which are being applied to the IVS vendors by GE are, in some cases, more severe than is required by the DORIAN system. In some cases, the performance requirements, as established by the Air Force, are well understood. In other cases, the specification is a considered choice based on a desirable characteristic which appears obtainable at little penalty. It is recognized that these matters deserve continued intensive attention, but there appears to be no instance where a significant problem is being created. Detailed discussions with Aerospace personnel involved in formulating the specifications indicated that each issue of concern to the Committee was recognized by Aerospace and was under consideration.

b. Light Level Performance

No formal specification has yet been made. The revised Wiener spectrum indicated as forming the current requirement was a matter of disagreement between Aerospace and GE. It appears that, assuming the more favorable IVS illumination as a result of using all the diverted light below 15^{o} sun angle, the anticipated specification is reasonable with a questionable area remaining in the region of high illumination and low modulation. There is a question about the specification of Wiener spectrum at 100 feet per cycle. For purposes of vendor selection and proof of feasibility of devices, it appears desirable to agree to a Wiener spectrum box outline (see Figure 1) quickly and refine it as necessary later.

c. Dynamic Range

The IVS is required by GE to operate over 0-600 μ rad/sec. The 600 μ rad/sec is considered by GE to represent both open loop performance and residual rate at end of slew plus 3 seconds. It appears that in either case the number could be lower, but the large capture rate requirement is stated to be achievable by all vendors. The Air Force, however, should consider carefully the specification of open loop performance with the goal of best optical performance without IVS lock-on.

d. Linearity

The null region requirement of ± 10% monotonic appears reasonable. The large signal region requirement of ± 25% monotonic with no saturation until 600 μ rad/sec is overly severe, but does not seem to limit the IVS vendors.

e. Accuracy

20 μ rad/sec. This value seems achievable and reasonable, although a slightly larger value could be accepted in view of the remainder of the budget contributions to the over-all specification of 42 μ rad/sec.

2. Recommendations

a. Determine the Wiener spectrum illumination region to be specified as soon as possible, but continue to study the implications of the specification intensively.

b. Obtain a tightened specification for open loop performance based on acceptable optical performance without IVS lock-on.

c. Monitor the IVS specifications levied by GE and insure that the performance of the IVS under conditions of good DORIAN performance [redacted] is not jeopardized by attempting to meet the extremes of the specification and, similarly, to insure that unessential complication of the IVS is not introduced.

III. IVS SELECTION

1. General Observations

In the Committee's judgment, none of the subcontractors exhibited a complete understanding of the possible behavior of his own system. This may be an unfair judgment. The Committee believes, however, that in the best interests of the MOL Program, a basic understanding of the Goodyear and Hycon systems should be developed before a final selection between them is made. Considering not only the immediate problem of the current MOL Program, but also the future, e.g., the search for higher resolution, one should also include the Itek system in this analysis. Since the three systems operated on different principles, the Air Force should thoroughly understand these differences and examine the limitations of each in environments other than those now specified for MOL. It is likely that each scheme will have special advantages in particular environments. It may also result that even in the specified MOL environment of rates, contrasts, light levels, etc., peculiar advantages or difficulties will be found.

A basic understanding of the several systems would permit an analysis which could answer, for example, such questions as:

As presently mechanized, the Itek system works on information in the high frequency part of the Wiener spectrum of the scene. Goodyear and Hycon work on much lower spatial frequencies. What are the limitations or possibilities in applying the Itek principle to other parts of the spectrum? What part of the spectrum should be used by the sensors? For example, is there a band of spatial frequencies over which all scenes have similar Wiener spectral intensities? If so, which of the three systems can best be optimized to work in this band, and what advantages, other than scene-insensitivity, are gained? Goodyear works with quantities which are quadratic in illumination level, while Itek and Hycon are intrinsically linear in illumination level. Hence, one would expect the Itek and Hycon principles to degrade more gracefully as one designs for lower and lower light levels. Are there interesting light levels at which this phenomenon has a useful effect?

The Committee would feel more confident in a final selection if there was available an evaluation of all of the systems within a framework as basic as that suggested by the preceding questions.

2. Subcontractor System Evaluation

a. Itek

The Itek system works by integrating the effect of image smear over a period of about 44 ms. The resulting smoothing effect reduces the high frequency content of the Wiener spectrum of the image, and the servo generates a compensating motion which maximizes that spectral content of the image. The spectral band in question, said to be around fifteen feet per cycle, is such that the Itek system will be inherently more sensitive to image focus than the others.

Since the Itek device works on scene content in the region of fifteen feet per cycle, the present specification, which is keyed to wave lengths of 100 feet per cycle, is not directly applicable to its design considerations.

Itek has chosen to work with a standard vidicon and standard TV scan rates. This gives Itek a sampling system with a particular fixed upper limit on its bandwidth, and fixes the integration time in a not very controllable way. It is likely that an optimum system using these principles would require both an integration time different from the present 44 ms, and an internal sampling rate different from 30 scans per second. The TV method can be made to work, but the approach has not progressed far enough to be considered a candidate for DORIAN.

Itek representatives stated that the addition of an image intensifier ahead of the vidicon would increase the light sensitivity and have certain other advantages.

On an engineering basis this requires handling high voltages in the image intensifier which are undesirable if other means are available.

b. Goodyear

The correlation device is in an advanced stage of development, and probably will be suitable for the DORIAN system. It operates on quantities which are quadratic in both illumination and modulation (unless slicing takes place). The full implications of these facts are not understood by the Committee. However, such a system is normally plagued by the basic limitation of correlation techniques when used for servo purposes. If the true correlation of the compared scenes is low, the uncertainty of the calculated or derived correlation is very large. This results in noisy or spurious signals and attendant servo stability troubles. While the method of using and inserting the IVS signals into the scan mirror servo may protect it from spurious commands, this limits the usefulness of the correlation method. Roughly, the true correlation of the compared scenes must be high (above 70%) to have a certainty of the derived correlation value better than 50%, which probably means the correlation device will require frequent recycling under actual scene conditions. However, the long focal length and consequent narrow acquisition angles of the DORIAN system seems to promise sufficiently high actual correlation between the stored and compared scenes that the method is expected to work. The practical response when recycle time is considered may be somewhat slower than described. This correlation device having no moving parts is passive in a mechanical vibration producing sense.

The Goodyear device works on what could be called a "matched filter" technique. Considerable analysis is available on this technique, most of which would have to be modified somewhat to include the effects of the large and variable "dc" component of the optical signals. It is not yet fully clear what spatial frequencies in the scene are important to the operation of the present Goodyear device, although it is probably the lower frequencies. (This is evidenced by the fact that the system is insensitive to defocus.) An analysis in terms of matched filters might suggest ways of optimizing this frequency selection against focus changes and changes in scene.

The contractor's belief that his "dynamic null" problem is an artifact of the simulator seems to the Committee to be correct. However, the question should be examined with greater analytical power than the Committee has seen applied to it. The Committee has already suggested certain additional tests and a good analysis may suggest more definitive ones, or even show that present data are already adequate.

The subcontractor showed that his correlation can be used for contrast enhancement, but his discussion was inadequate to demonstrate exactly how this capability could be effectively exploited. Neither did he show whether, were it exploited, it would lead to useful advantages in performance. The Committee believes that more understanding is required before the usefulness of this feature can be evaluated.

The subcontractor mentioned several modifications to his system which would add new features not covered by the present MOL requirement or specifications. The Committee suggests that the Air Force may be interested in having these matters explored further. However, the Committee does not believe that they are relevant to the choice that must soon be made.

c. Hycon

The Hycon system makes a comparatively direct measurement of velocity. Its operation can be, if the designer chooses, linear in applied illumination and contrast. Its operation depends for the most part upon principles well known and understood in electrical engineering. The vendor has ready control over the spatial frequencies to which his system is sensitive, and has exercised this control for optimization.

Even within the framework of his present mechanization, he has a wide latitude of design choice in selecting the important parameter of operation. The principles he exploits can be adapted to designs for an even wider range of operating conditions.

It appears to the Committee that Hycon's remaining problem, in the present instance, "Scalloping," can be solved adequately by shaping the illumination across the field. Analytically, the problem is like that of illuminating an antenna for minimum side lobes or designing a filter for minimum echoes. Analysis provides both a solution and an estimate of its limitations.

Hycon asserts that the weight and bulk of their system can be reduced. This appears likely. The signal drop-out problem experienced in test appears adequately handled by the feedback memory technique. This device has a mechanically active element; namely, the rotary chopper disc which rotates at 30 Hz. With careful attention to bearings and balance, the residual vibratory disturbance should not cause difficulty. This device appears at this writing to be the most applicable to the DORIAN system IVS requirement.

IV. CONCLUSIONS

1. With respect to the selection of a contractor and system for the MOL mission, the Committee agreed that:

a. On the basis of information now available, either Goodyear or Hycon could be selected with relatively high confidence of success.

b. There is no reasonable possibility that, by the time a decision must be made, the level of confidence in Itek will be comparable to that in either of the others.

c. A selection between Goodyear and Hycon will depend upon engineering, and possible programmatic, factors which the Committee is not prepared to judge in this report.

2. With respect to a consideration of whether to terminate one or more contractors now or when to terminate all but one, the Committee observes:

a. There seems to be no immediate benefit to the MOL Program in continuing Itek.

b. The advantage in continuing both of the other contracts for the present are: first, the value of competitive pressure and, second, the possibility that further exploration of some of the engineering factors (e.g., weight, power, vibration, reliability) will show a clear advantage to the MOL Program in one of the approaches.

c. The principal disadvantages to continuing more than one contractor probably li e in the costs of testing and in the demands on GE and Aerospace talents.

V. RECOMMENDATIONS

a. It is recommended that the present phases be completed on all devices, except that further tests be conducted by General Electric only on the Goodyear and Hycon devices, and that the Itek device be sent to the Avionics Laboratory for further study. It is recommended that the Goodyear device be carefully reviewed for possible correlation with real scenes that may limit its effective response.

b. It is recommended that the Hycon device be reviewed for correction of the signal drop-out that may be experienced under real scene conditions. Attention should be given to bearing noise vs. life in the Hycon device rotor to insure that the residual 30 Hz mechanical disturbance does not cause any difficulty in the adjacent optical or camera units.

c. It is recommended that both the Goodyear and the Hycon devices be continued even though they both probably will not meet the low modulation-high illuminance corner (Wiener spectrum diagram - Figure 1) of the present tentative specification.

d. It is recommended that upon successful completion of the test program, an early final choice be made between the Goodyear and the Hycon devices.

VI. SUPPLEMENTARY SUBJECTS

1. Simulator

The IVS simulator appears to be a good design, but there are certain defects which seem to penalize the Goodyear more than the Hycon device. The first, which is fundamental, is that reasonable space limitations require short working distances from device to target platen, so that the field angles are much higher than those to be encountered in MOL. It is recommended that General Electric and Goodyear explore this to their mutual satisfaction so that allowance can be made in the interpretation of test results.

A second defect is the specular reflection from the semi-gloss photographic paper used in the target. It should be possible to reduce this either by good matte paper or by combining high gloss (or ferrotyped) paper with properly placed flood lights. It is recommended that this be done.

There are uncertainties about the behavior of IVS on three dimensional targets with shadows. Since a three dimensional model is already completed, it is recommended that the engineering models of Goodyear and Hycon be tested on the simulator using this model as well as the flat print for target. The high gloss paints on this model may have to be dulled. More important, it should be recognized that even with a model in correct scale, the perspective will be distorted by the short working distance which may complicate IVS performance, so that test results should be interpreted with caution.

2. Clouds

At the request of the Air Force, all contractors spoke to the question of IVS operation in the presence of clouds. Ingenious ideas came forth, but all discussion was speculative.

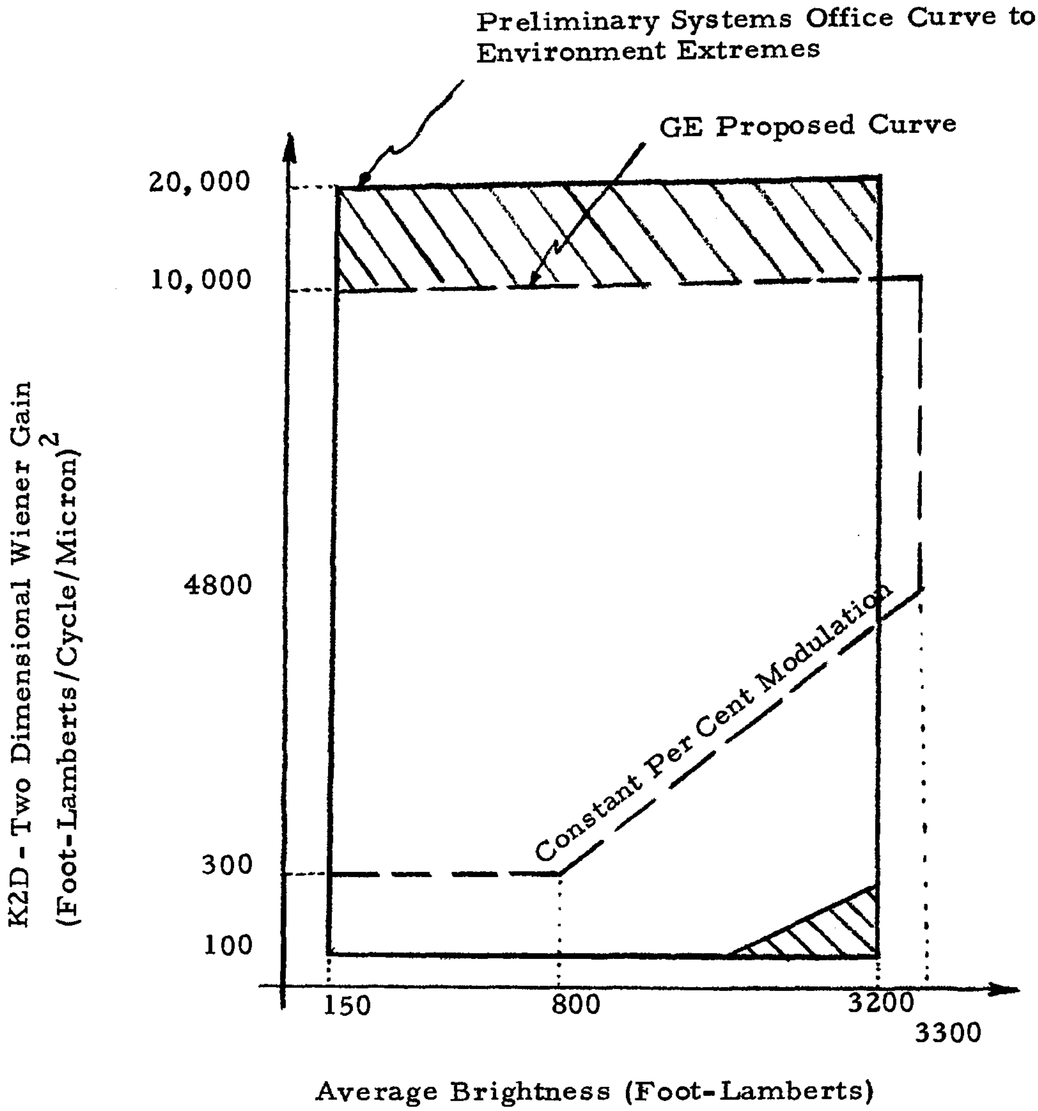
The Committee believes that the Air Force must clarify its own understanding of the requirement to operate in the presence of clouds, before this issue can be used as a criterion for choice between IVS systems. Indeed, the Committee believes that this clarification should take place before money is spent with contractors in attempting to meet a cloud requirement.

The basic question is: How important is it for the system to operate in the presence of clouds? In the MOL environment, this spawns more complicated questions:

How often, when the primary target is obscured, can one successfully photograph an alternate? How good is the resulting photograph, and how much does this quality improve with good IVS sensing? What then are the requirements to be met by a useful IVS?

The Committee saw no evidence that the Air Force had addressed these questions, and recommends that none of the contractors be required to demonstrate their device's capability in the presence of clouds until it is better understood by the Air Force.

It is suggested that the open loop tracking capability to permit good photography if the IVS loses track in the presence of clouds be improved as much as reasonably possible.



Note: All data referenced to tracking mirror input at 80 nm altitude.

Figure 1. IVS Power Spectral Density and Brightness Operating Regime.