THE EFFECTS OF THE ENVIRONMENT ON OPTICAL SYSTEMS

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ABSTRACT

The environment in which an optical system operates has a pronounced effect on its performance. This paper covers the effects of temperature, atmospheric pressure and atmospheric interference on the performance of optical systems in airborne reconnaissance cameras. In particular, this paper discusses the effects of the above elements on the performance of long focal length optical systems such as those used for Long Range Oblique Photography (LOROP), and some of the ways that can be used to reduce or eliminate these effects.

INTRODUCTION

Operating an optical system in a changing environment can cause severe degradation to the user's imagery unless special precautions are taken. As mentioned above, the three leading and most pronounced elements that degrade optical system performance are temperature, atmospheric pressure and atmospheric disturbances. Of these three, temperature and atmospheric pressure can be compensated for. However, the effects of atmospheric disturbances, especially on long focal length systems, are difficult if not impossible to deal with. This discussion covers the operation of long focal length optical sensors from various aerial platforms.

THE ATMOSPHERE AND ITS EFFECTS

Temperature

The temperature of the optical system's environment is the easiest to control. Temperature affects the performance of an optical system in several ways. However, techniques exist which can eliminate and/or reduce these effects depending on the degree of compensation used. The two basic optical systems currently used on long focal length systems are refractive and reflective optics. This discussion deals with the environmental effects on refractive systems only, as these are by far used most in general photographic systems.

Both steady state and transient conditions must be considered when dealing with temperature. Of the two, transient temperatures are harder to tolerate and compensate for. During temperature transients, the change in temperature experienced by the lens introduces strain in the glass of individual lens elements. This results in a shift in focus, and a lens modulation reduction resulting in an overall reduction in contrast ratio at the film or sensing media. Focus shift can be compensated for by using an autocollimating, closed-loop, autofocus technique. With the proper mechanization, this technique can reposition the effective focal plane at a plane of best focus. However, while the optical system is undergoing this transient condition, the system's peak resolution becomes degraded.

The other effect of temperature is the shift in focus due to finite stable ambient temperature conditions. For each temperature, there is a discrete focal position. This position can be found also by using an autofocus system, or the shift for a given temperature can be measured under controlled laboratory conditions and the focus adjusted manually.

Several factors cause focal shifts under stable temperature conditions. Different lenses using different glasses for the various elements and different materials for the lens barrel exhibit different focal shift characteristics for a given temperature change. Depending on system makeup, the shift can be positive (increase in focal length) for an increase in temperature, or it can be negative (decrease in focal length) for the same temperature change. Added to this is the physical growth characteristics of the material between the lens mounting flange and the image focal plane. Stabilization time (the time it takes for a lens to reach its stable condition) varies greatly depending on the finite value of the temperature change, and the size of the individual optical elements. A 66-inch focal length (fl), f/8 optical system may take approximately 12 hours to overcome a 20° temperature step function, whereas a 66-inch fl, f/5.6 system may take as long as 20 hours to reach stability.

Several methods are used to reduce the effects of focus shift due to steady state temperature differences including:

- Special compensating mounts which change dimensions to compensate for the focus shift.
- Composite materials which, on long focal length systems, reduce the effects of barrel dimension changes associated with temperature changes leaving basically only the effects of the lens itself.

Figure I shows the effect of focus shift and resolution performance associated with a temperature change of 28° F. The two curves show the effects of resolution with and without the use of autofocus. As discussed above, even with autofocus, the resolution obtainable under transient conditions becomes less than optimum, and only after the system reaches equilibrium does the resolution return. These tests were performed on a 66-inch fl, f/8.0 optical system mounted in a KS-127 camera system. Notable in these tests are the loss of performance due to temperature transient conditions, the resolution achievable with compensation during transient conditions, and the time required to reach optical stabilization. The tests demonstrate the sensor's reaction when stored at room temperature, and then subjected to a flight condition where the sensor compartment is heated to 100° F (similar to the temperatures found in the RF-4 aircraft).

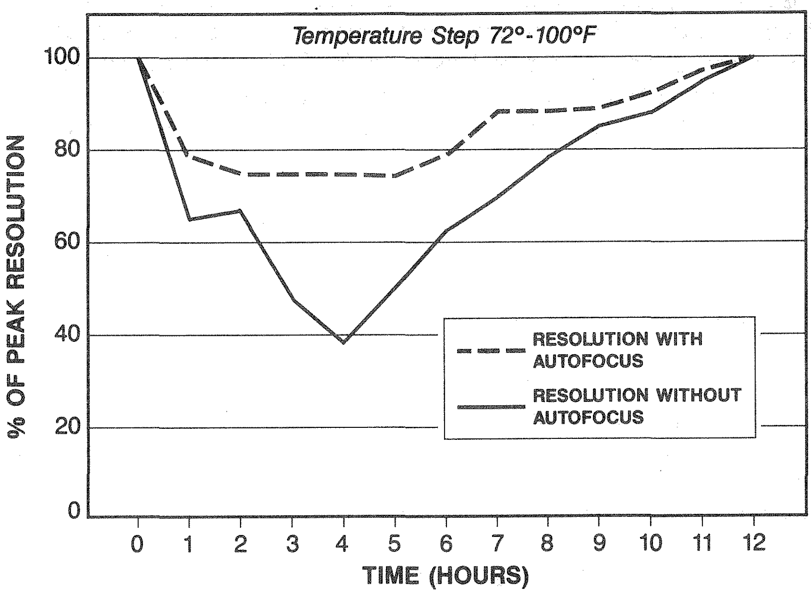

Figure I Focus Shift and Resolution vs. Time

Two approaches are available to improve sensor performance under the conditions described above. The first would be to store the sensor for a minimum of 12 hours prior to the mission at the sensor compartment operating temperature. The second is to use a thermal control system and maintain the sensor's optical components at the preflight conditions. Tests have shown that under controlled conditions, a resolution performance of 90 percent or better can be maintained.

Atmospheric Pressure

Atmospheric pressure is the second element which affects optical system performance. Unlike the effects of temperature, the effects of atmospheric changes such as those encountered by a sensor at various altitudes is predictable. As the sensor moves to higher altitudes, the atmospheric density becomes thinner causing the focal point of the image to move away from the film plane and closer to the lens. This requires that the effective distance between the lens and the image sensing media be made shorter as the sensor moves higher into the atmosphere. The following will provide compensation for this effect:

- Direct derivation and test with a resultant mechanical change (shift) in the distance between the sensor's lens and focal plane.
- Autocollimating autofocus techniques resulting in an automated mechanical compensation.
- Sensing the ambient pressure and electrically driving a mechanical focusing mechanism to a predetermined position.

Figure 2 shows the focus shift as compared with altitude for a 66-inch fl, f/8.0 optical system.

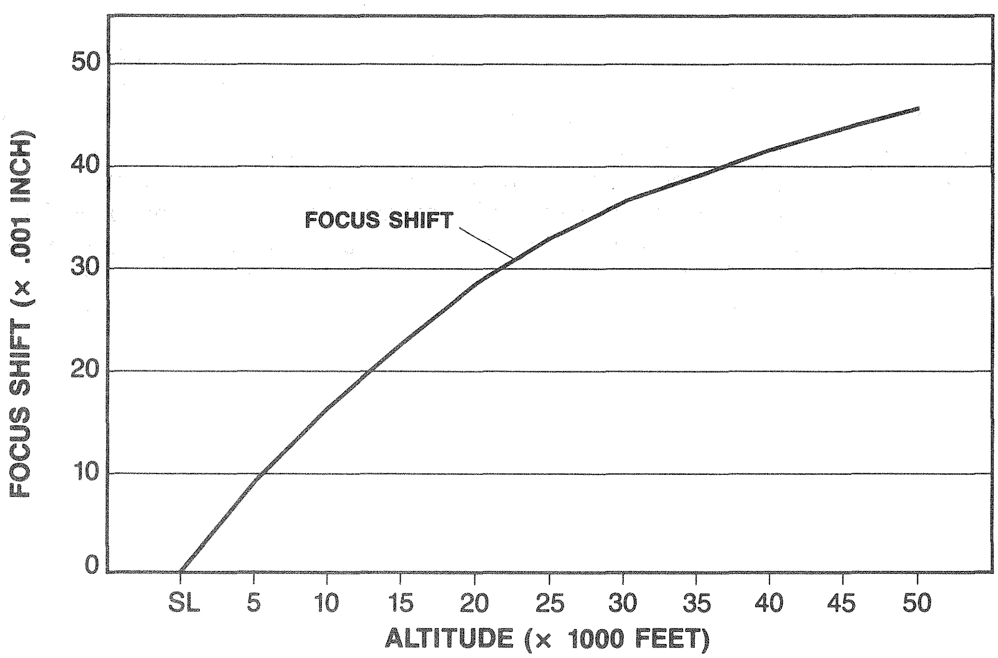

Figure 2 Focus Shift vs. Altitude (Pressure)

Atmospheric Disturbances

Atmospheric disturbances such as thermal gradients, cloud cover, turbulence, and airflow across the sensor platform window also contribute to sensor performance. These disturbances are the most elusive contributors to image degradation and are difficult if not impossible to compensate for. Examining the RF-4C aircraft as a sensor platform, it has been shown that different aircraft velocities cause different airflow characteristics across sensor windows. Papers presented by Mr. R. Fisher at SPIE symposiums held August 1977 and August 1981 discussed the effects of airflow and boundary layers created during aircraft flight, and the imagery degradation caused by this airflow.

Other factors affecting aerial photographic performance include cloud cover with the resultant loss of contrast, the lack of shadow detail associated with most aerial photography, and thermal turbulence which is at its peak approximately 2 hours after sunrise. Photographing through this turbulence can severely reduce sensor performance. An exaggerated example of this is similar to looking at an object on the other side of a hard-surfaced area on a warm, sunny day. As this object is observed, distortions of the object due to air motions generated by the heated surface can be noticed.

Another important degrader of sensor performance is the amount of pollutants in the atmosphere. The effects of these pollutants increases as the sensor depression angle decreases with respect to the horizon. At depression angles of 14° or less, these pollutants become excessive to the point that, regardless of the degree of pollutants, the effect due to the long slant ranges severely limits the information gathering capability of the sensor.

CONCLUSION

Even though the environment plays a major part in the ability of a sensor to perform to its ultimate capability, other factors not discussed are also important. However, in most cases, these can be compensated for with little or no residual effect. These items include, but are not limited to, forward motion of the vehicle in which the sensor is mounted, roll, pitch and yaw motion of the sensor or sensor vehicle, and range to the target. These items can readily be measured and compensated for with a minimum of effort as are the pressure altitude and steady state temperature described earlier. Temperature transients and the unknowns associated with the atmosphere are harder to measure and compensate for, and also affect the final outcome of the sensor's performance.