LASER IGNITION OF ARCTIC OIL SPILLS ENGINEERING DESIGN

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ABSTRACT

The design of a system which will enable helicopter deployment of the Laser Ignition of Arctic Marine Oil Spills technique, introduced at last year's seminar, is presented. The design includes methods for aligning and focusing the lasers, powering and cooling them and the associated electronics, stably pointing the lasers at an oil pool in the presence of helicopter vibrations, rangefinding, controlling the system, and mounting the components in an airworthy manner.

INTRODUCTION

Over the past four years, a novel dual-laser approach for ignition and burning of Arctic oil spills has been developed under the sponsorship of Environment Canada[1,2,3]. The process may be summarized as follows: A continuous-wave (CW) carbon dioxide laser is used to heat a portion of the surface of an oil pool to its flashpoint temperature and simultaneously establish a thermal field within the oil which will not quench a nascent flame. A focused, pulsed laser beam then provides energy which creates a momentary "spark" above the oil surface to ignite a fire. Previous work has shown that, to ensure ignition of properly preheated oil, the pulsed laser should provide a fluence of at least 10 J/cm^2. In addition, to minimize the preheating time required to start a self-sustaining fire, it is generally desirable to use a CW laser

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providing as much power as is possible. Presently available lasers suitable for helicopter mounting supply up to 1000 W.

To utilize this technique for ignition of oil in an Arctic environment from an airborne platform, the sequence of events shown in Figure 1 must be followed. The sequence begins with "target acquisition": The system operator locates the position on the oil pool at which the lasers are to be aimed, points the lasers at that position, and confirms that the beams are in fact where the operator thinks they are pointed. The pulsed laser beam is then focused to the required fluence at the oilpool surface by adjusting the separation between two optical elements comprising a reverse Cassegrainian telescope. Next, laser firing commences and continues until a self-sustaining fire is established. During this period, the beams must not be allowed to drift or oscillate over such a large region as to preclude efficient heating of the oil.

Clearly, an air-deployable Laser Ignition of Oil Spills (LIOS) system requires numerous interacting components which must:

1. Include a pulsed laser which is focused to provide sufficient fluence to ignite, from a distance, fires on preheated oil pools;
2. Include a CW CO_2 laser producing up to 1000 W of power which is optically configured to irradiate an oil pool with the required preheating intensity;
3. Incorporate a means of aligning and holding the laser beams on target despite helicopter movements and vibrations;
4. Provide sufficient power and cooling capability to operate all of the components;
5. Be installable in a Sikorsky S61 or comparable helicopter without affecting airworthiness or safety; and
6. Be operable by an aircraft maintenance technician.

The design of such a system has now been completed[4], and is described herein.

OPTICS

As illustrated in Figure 2, an optical layout has been designed which incorporates in one integral platform the two lasers and optical trains for focusing, rangefinding, and beam alignment. Except for the lasers, all of the components are mounted on a rigid optical table, component #1. The two lasers (components #15 & #16) lie on a shelf below the optical table, and their beams are reflected to the table surface by several small mirrors (indicated as components #9 & #10). This entire structure is isolated from high-frequency helicopter vibrations by suspending it on damped springs.

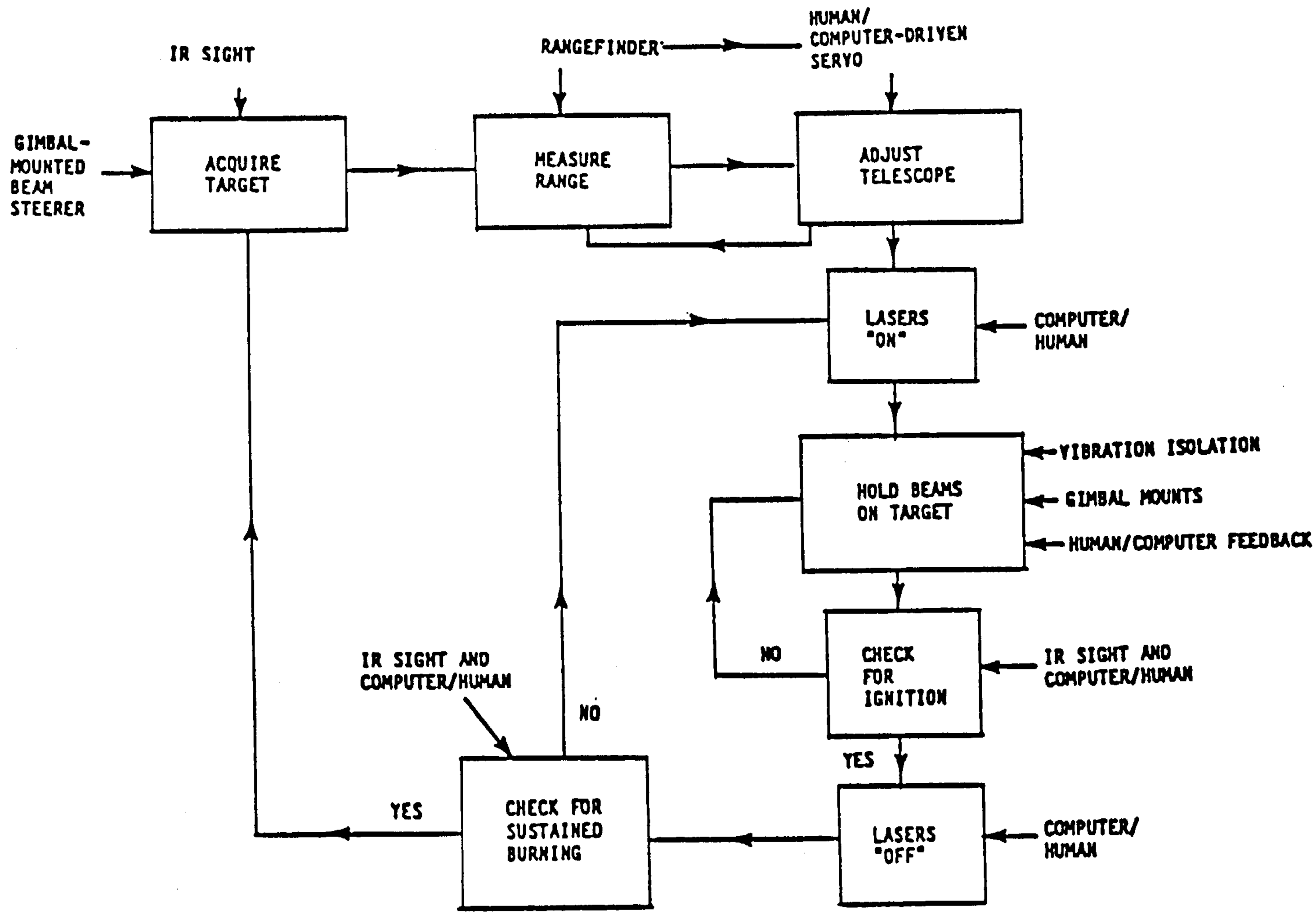

FIGURE 1 - LASER IGNITION SEQUENCE

COMPONENTS

1. Optical Breadboard
2. Rangefinder (Option B)
3. IR Scanning Radiometer for Targeting System
4. Gimbal Mount for 10-12 in. Optic
5. 12 in. Diameter Gold Coated Mirror with 2 in. Hole (Option A)
   12 in. Diameter Dichroic Pyrex Window
6. -9 in. F.L., 1.5 in. Diameter AR Coated GE Lens mounted in 10 in. Diameter Ring
7. 2 in. Diameter, AR Coated (at 10.6 μm) GE Flat mounted in 14 in. Diameter Ring
8. 2 in. Gold-Coated Mirror mounted in 14 in. Diameter Ring
9. Pulsed Laser Beam Steering Mirror
10. CW Laser Beam Steering Mirror
11. 10 in. Diameter, 60 in F.L. Gold-Coated Parabolic Mirror
12. 4 in. Linear Translation Stage
13. DC Drive Motor and Electronics for Feedback Control
14. Beam Targeting System
15. CW Laser
16. Pulsed Laser
17. CW Laser Beam Diverging Lens

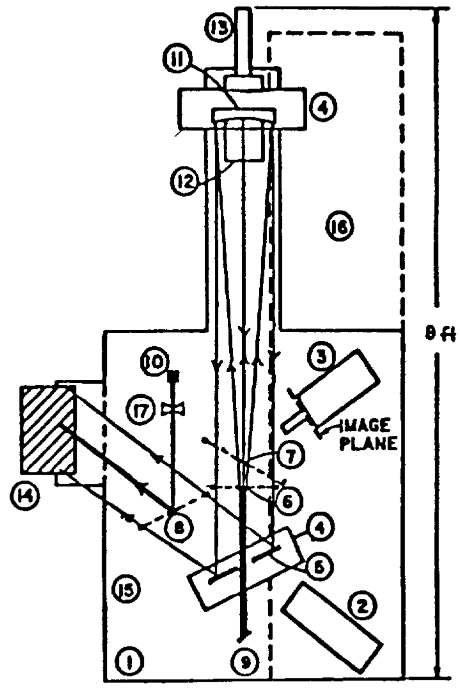

FIGURE 2 - LAYOUT OF L.I.O.S. OPTICAL SYSTEM

Pulsed Laser Selection and Focusing

The pulsed laser (component #16) will be a Lumonics Model TEA-103, selected on the basis of its weight, size, beam quality, energy per pulse, repetition rate, structural integrity, power requirements, efficiency, and cost. The laser will be operated in the unstable resonator configuration, providing 8 J per pulse with a nominal beam divergence of 0.8 mrad.

Assuring that the pulsed beam is focused at the surface of the oil pool to a fluence of at least $10J/cm^2$ is the most critical optical task in this program. The beam, after being transmitted to the table top, is focused by a reverse Cassegrainian telescope, reflected to a pointing mirror, and thence to the oil pool. To minimize the size, and thus the cost, of the focusing optics, the telescope has been designed to operate at the minimum acceptable helicopter hovering altitude of 20 m. To optimize the ground area which can be covered from a fixed hover (as constrained by the divergence of the CW laser, discussed later) a capability to continuously vary the effective focal length of the telescope between 20 and 30 m has been included.

The path of the pulsed laser beam is shown in Figure 2 as directed lines. It first passes through a small hole in reflector #5 (the full function of which is discussed later), and impinges upon an anti-reflection coated, -22.8 cm focal length, 3.8 cm diameter germanium lens (component #6), which causes the beam to diverge. The diverging beam passes unaffected through a germanium flat, also coated so as to be non-reflective at the laser wavelength (component #7, discussed later) and, after having expanded to a diameter of about 20 cm, strikes the movable 152.4 cm focal length, 25.4 cm diameter focusing mirror (#11). The beam is reflected back along its original path and, now slightly converging, is directed by component #5 onto the pointing mirror #14 and subsequently onto the oil pool. The distance from the focusing mirror to the location at which the beam achieves its minimum diameter can be altered by changing the separation between that mirror and the diverging lens. To vary this effective focal length from 30 to 20 m, the separation between the two elements should range from 1.377 to 1.421 m. For this purpose, the focusing mirror is mounted on a motorized translation stage (#12).

The focusing of the laser will be controlled by either of two methods: A) By using the focusing mirror to form a visible/infrared image of the oil pool, and varying the separation between the two telescope components until this image is in focus; or B) By measuring directly the distance between the telescope and the oil pool, and using it to calculate the appropriate component separation. Option A is called passive focusing, option B is active. The optical layout of Figure 2 has been designed to accommodate either scheme.

With passive focusing, the image formed is comprised of radiation from scattered sunlight and infrared energy emitted in response to heating by the lasers. It therefore has a fairly broad spectral distribution, containing energy at wavelengths ranging from the visible to the far-infrared, which propagates along nearly the same path as the pulsed laser but in the opposite direction. Most of this energy is split from that path by the germanium flat #7, which, although coated to transmit energy at 10.6μm without reflection, is highly reflective for wavelengths shorter than about 5μm. When focused, a crisp image of the oil pool will be formed at the image plane indicated near component #3. The image plane is located at a distance equal to the sum of the focal length of the diverging lens and the optical element separation. Therefore, by the principle of reversibility, the laser will be focused on the oil pool when the image of the pool is in focus. A focus analyzer (component #3), similar to those used in self-focusing zoom lenses, could be located at the image plane and used to drive a servo motor (component #13) to move the imaging optic in the proper direction to optimize focusing. Although this passive focusing technique is conceptually simple, its accuracy and cost cannot be determined without experimentation.

The active focusing system utilizes a device to measure the distance to the oil pool, a lookup table or equation from which to determine the proper telescope component separation for the measured range, and a controller to set that position. The most accurate means currently available for measuring distances is to use a laser rangefinder, such as the Canadian manufactured Optech Model 60. This device uses a diode laser, radiating at a wavelength of 0.9 μm, to measure distances up to 150 m with a 30 cm accuracy, which is sufficient for our needs. According to the manufacturer, it will have no difficulty in measuring the distance to an oil pool even when receiving only backscattered laser radiation from a 45° angle of incidence. If used, the rangefinder will be incorporated into the optical system by substituting a dichroic pyrex window, coated to reflect in excess of 95% of the incident CO_2 laser radiation at 10.6μm but transmit more than 70% of the near-ir radiation used by the rangefinder, in place of the simple gold-coated pyrex mirror used in passive focusing to direct the beam to the pointing mirror (component #5). By positioning the rangefinder as shown it can be aligned colinearly with the pulsed laser. To be used as an automated focusing system, the distance measured by the rangefinder will be fed into a computer which calculates the appropriate focusing mirror position and drives a servo to move the mirror as necessary.

CW Laser Selection and Alignment

On the basis of its size, weight, ruggedness, cooling requirements, power requirements, gas consumption, ease of operation, and cost, the Laser Corporation of America (LCA) Falcon 800 was selected as the CW laser. Its beam emerges from the laser head with a diameter of 32 mm and has a far field divergence of 1.5 mrad full angle. It is capable of producing up to 1000 W.

Previous work[1] has shown that, when incident upon the oil surface, the CW laser beam should describe a circle having a diameter between about 6 and 12 cm, or an area between 28 and 115 cm^2. For this constraint to be satisfied from a 20 m hover, the beam divergence must be increased over that which the laser provides naturally. It has been found that the maximum ground area can be covered when the divergence is increased by passing the beam through a -20 m focal length lens. Then, the beam can be aimed over vertical angles ranging from 0 degrees (straight down) to 49 degrees, corresponding to the slant ranges of 20-30 m discussed above, without the irradiated area at the oilpool surface becoming excessive.

The CW and pulsed lasers are aligned colinearly without substantial power losses by using the "hole" in the pulsed beam, formed by the hole in reflector #5, as an area in which to mount additional optical elements. In particular, the relatively small diameter CW laser beam is reflected from a mirror mounted within the hole, indicated as component #8. This mirror is held in place by three small prongs which extend from a ring having a diameter large enough to surround the expanded pulsed beam, thereby minimizing power losses to the optical holders. Both laser beams are then directed to the oil pool by mirror #14.

POWER AND COOLING

The Falcon 800 laser consumes 21 kW of electricity to supply 1 kW of laser power; cooling water is used to reject the 20 kW of waste heat. In a helicopter there can be no external supply of water, so the water must be air-cooled. The simplest way to cool the water, by using a commercially manufactured heat exchanger able to dissipate the full 20 kW, was found to be also the best solution. Assuming an ample supply of Arctic air is available at 0-5°C, then three Lytron Inc. Model 6321G3 heat exchangers, will adequately cool the water. These units are small, lightweight, and inexpensive.

The installation of the LIOS system requires the availability of a large amount of electrical power for the CW laser (21 kVA). The power requirements of all the other electrical equipment associated with the LIOS system, and the pulsed laser combined do not approach this level of power demand. In fact, the sum of the power required by all units not including the CW laser will be less than 4 kW, which can easily be satisfied by existing aircraft power supplies.

For the S-61R helicopter, there is a 300A, 28V DC generator, and two 20 kVA, 115V AC, 400 Hz generators. An existing APU is mechanically linked to the rotorcraft gearbox for use as a starter unit. Although its power output would be sufficient for the needs of this system, installation of a generator would require major modifications to the helicopter. Typical aircraft operations will require roughly 200 A DC, and approximately 28 kVA AC power. This will leave about 1 kW of DC power and 4 kW of AC power, accounting for the fact that electrical loading should not exceed 80% of the generator capacity as specified in the Canadian Department of Transport Engineering and Inspection Manual[5].

All of the electrical units will require power in the standard 120V, 60 Hz AC format, and hence, either power inverters or converters will have to be utilized. Typical efficiencies of these units are 70% for inverters (AC to DC), and somewhat less for the power converters (AC to AC) -- perhaps 50-60%. This will dictate a power availability of 7 to 8 kW. This load could well be satisfied by the aircraft power systems, if the unnecessary aircraft equipment were shut down during the operation of the LIOS system. However, the requirement of 21 kVA power for the CW laser clearly specifies that some sort of auxiliary power be available. Installation of an Auxiliary Power Unit (APU), coupled to a suitable AC generator, can easily supply all the power requirements of the CW laser, and perhaps some of the associated electronics as well. The CW laser requires AC power with the following characteristics:

230 VAC; 3 phase; 60 Hz.

Standard aircraft APU units are available from 28 HP (21 kW) up to 150 HP (112 kW). The typical APU's, however, are in the 40 HP (30 kW) to 80 HP (60 kW) range. Assuming a generator efficiency of 75%, the 21 kVA power requirement would translate to a power capacity of 28 kVA required from the APU.

The Turbomach Division of Sundstrand manufactures a complete line of compact, lightweight APUs for airborne systems. A generator is necessary to convert the mechanical output of the APU into electrical power. Such generators are available from Bendix. An alternative would be to modify a ground-based electrical power unit for mounting in the helicopter.

Installation of an APU complicates matters from the point of view of airworthiness requirements compliance; many safety measures concerning airworthiness must be satisfied, such as fire protection, a protective housing for the APU, and ventilation of the housing.

Since no APU installations of this capacity have been developed or approved under Supplemental Type Approvals (STA) in Canada or Supplemental Type Certificates (STC) in the U.S., one such installation will have to be developed for this particular system. In order to avoid major helicopter modifications, the system must be independent of aircraft fuel supply and main power bus. As such, this design must include a separate fuel system and, as indicated above, the precautions necessary to maintain airworthiness, though complex, must be implemented.

The generator, fuel tank, and fire extinguishing system are off-the-shelf items which may be acquired from a multitude of suppliers. The APU housing, ventilation system, and refuelling system will have to be custom designed. Restrictions on the design will be dictated by the APU components chosen and helicopter cabin layout.

TARGETING SYSTEM

The output of both lasers is to be directed by a targeting mirror onto a selected oil pool. The laser beams can drift off target due to the combined effects of high frequency helicopter vibration and low frequency gross helicopter motion. The laser targeting system must compensate for the latter, keeping the laser beams on target for periods of up to 30 seconds with a centroidal drift not exceeding 2 cm. For a target range on the order of 30 m, this requirement translates into an angular deviation of 0.67 milliradians, or about 2 arc-minutes.

The basic components of the targeting system, as shown in Figure 3, are: a sensor that collects the target radiation and converts it to an electrical signal; signal processing electronics that process the sensor output signal to produce pointing error signals; a movable platform that permits isolation from disturbances to the pointing system and allows the sensor to compensate for helicopter motion; and a servo and stabilization system to control the platform position.

The large targeting mirror is mounted on the movable platform. Since the rotation of the laser beam about its axis of propagation is inconsequential in this application, the platform will be biaxial, consisting of an azimuth and an elevation stage, both driven by DC motors. The target should be stationary, have good optical contrast, and should be invariant with respect to rotation. These requirements are fulfilled by the thermal radiation emitted by the laser-heated oil spot. An infrared sensor that detects this radiation will be used to generate appropriate error signals to control the motion of the rotation stages.

Previous experiments[1] have shown that the oil temperature in the zone of laser irradiation exceeds 100 °C. while outside the zone the temperature is about half as high. These tests also showed that the oil takes from 1 to 2 seconds to reach its maximum temperature when irradiated with the CO_2 laser. Thus the laser-heated oil spot can provide a distinctive thermal signature for about a second, which should be ample time for the targeting system to react to shifts in the laser line-of-sight.

The choice of an infrared tracking system depends on performance, cost, and availability. A survey of infrared tracking schemes showed that an imaging tracker is the best choice for LIOS. An imaging tracker uses one or more detectors which produce video signals by means of a linear raster scan of the target scene. Examples of imaging sensors are TV cameras, linearly-scanned detector arrays, and two-dimensional electronically-scanned arrays. The video information is processed digitally to generate error signals proportional to the position of the target in the video image.

The imaging tracker consists basically of the infrared sensor and the signal processing electronics. A good candidate for the former is the Inframetrics Model 525, a scanning infrared radiometer that provides a TV-compatible video output. This instrument will be used to sense infrared radiation in the 8-12 μm range. This range is

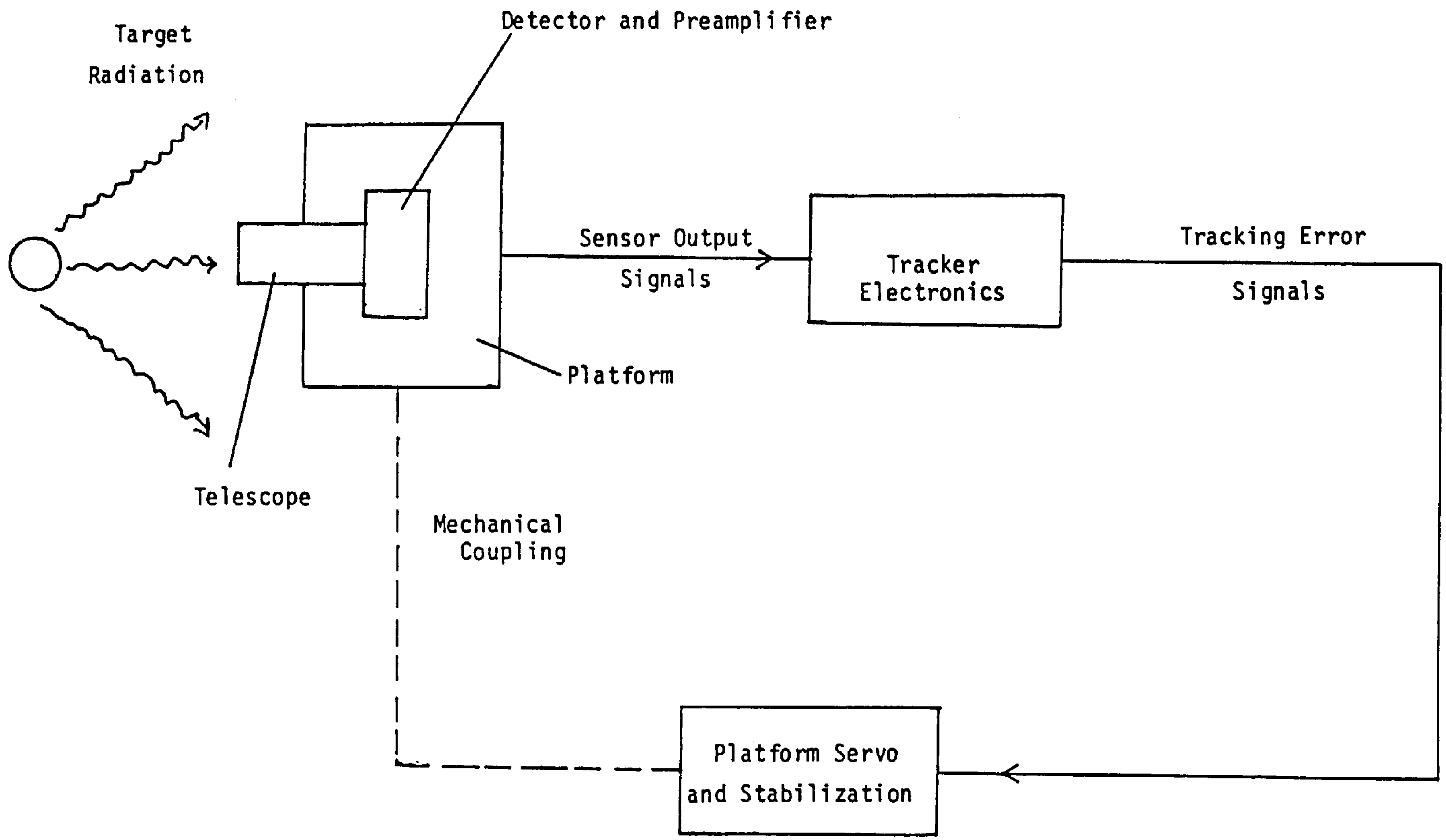

FIGURE 3 - TARGETING SYSTEM COMPONENTS

used instead of the 3-5 μm band because the target signal is stronger and there is less interference from solar radiation in this band.

The scanning radiometer is shown as component 3 in Figure 2. With this arrangement, the infrared image of the oil pool is aligned with the optical axis of both lasers. Motion of the targeting mirror results in a displacement of the scanner's field of view. The anti-reflection coated Ge flat minimizes the effect of backscattered laser radiation on the infrared image.

The video signal from the infrared scanner is processed by a DBA Systems Model 606 video tracker, which has a number of features that make it useful in a tracking application. For example, it can generate and display crosshairs superimposed on the infrared video image indicating the null tracking point. One can choose between either edge or centroid tracking modes. The tracker provides both analog and digital error signal outputs for ease of interfacing with servo components. An auxiliary video input is provided to enable one to mix externally generated signals with the composite video. A block diagram of the video tracker is given in Figure 4.

The video tracker is operated in the centroid tracking mode. The image of the hot spot on the oil pool is selected as the target by a thresholding operation, and the tracker determines the location of the hot spot centroid within the target scene. Error signals proportional to the displacement of the target centroid from the reference position are generated.

The targeting mirror is a flat, gold-coated glass mirror 24 inches in diameter and 0.75 inches thick. It is supported by a rigid mount that allows it to be attached to the movable platform. The targeting mirror platform consists of two servo-driven rotation stages that can point the mirror within a fraction of a milliradian. The most cost effective method of assembling the platform is to use a RT 300 rotation stage and a BG 200 goniometric cradle, both from MicroControle. The targeting mirror is mounted on the goniometric cradle, which in turn is mounted on the rotation stage. Both stages are driven by DC motors with integral tachometers and rotary encoders. The tachometers provide rate feedback to the servo controllers while the encoders indicate the angular position of the rotary stages. Limit switches are provided on both positioning stages as a safety precaution in case of control loss.

The servo controller takes the output from the video tracker and adjusts the gain and compensation for the control system. The controller is implemented in a microcomputer for flexibility in control law design. The microcomputer's digital outputs are converted into analog control signals by DACs (digital to analog converters) and fed into PWM amplifiers that drive the DC motors. In addition to handling the digital output from the video tracker, the microcomputer also accepts input from the rotary encoders and from a joystick. The former allows the angular position of the rotary stages to be displayed on the screen. This information can also be used to compute the target range if the helicopter altitude is also known. The joystick permits open loop control of the targeting

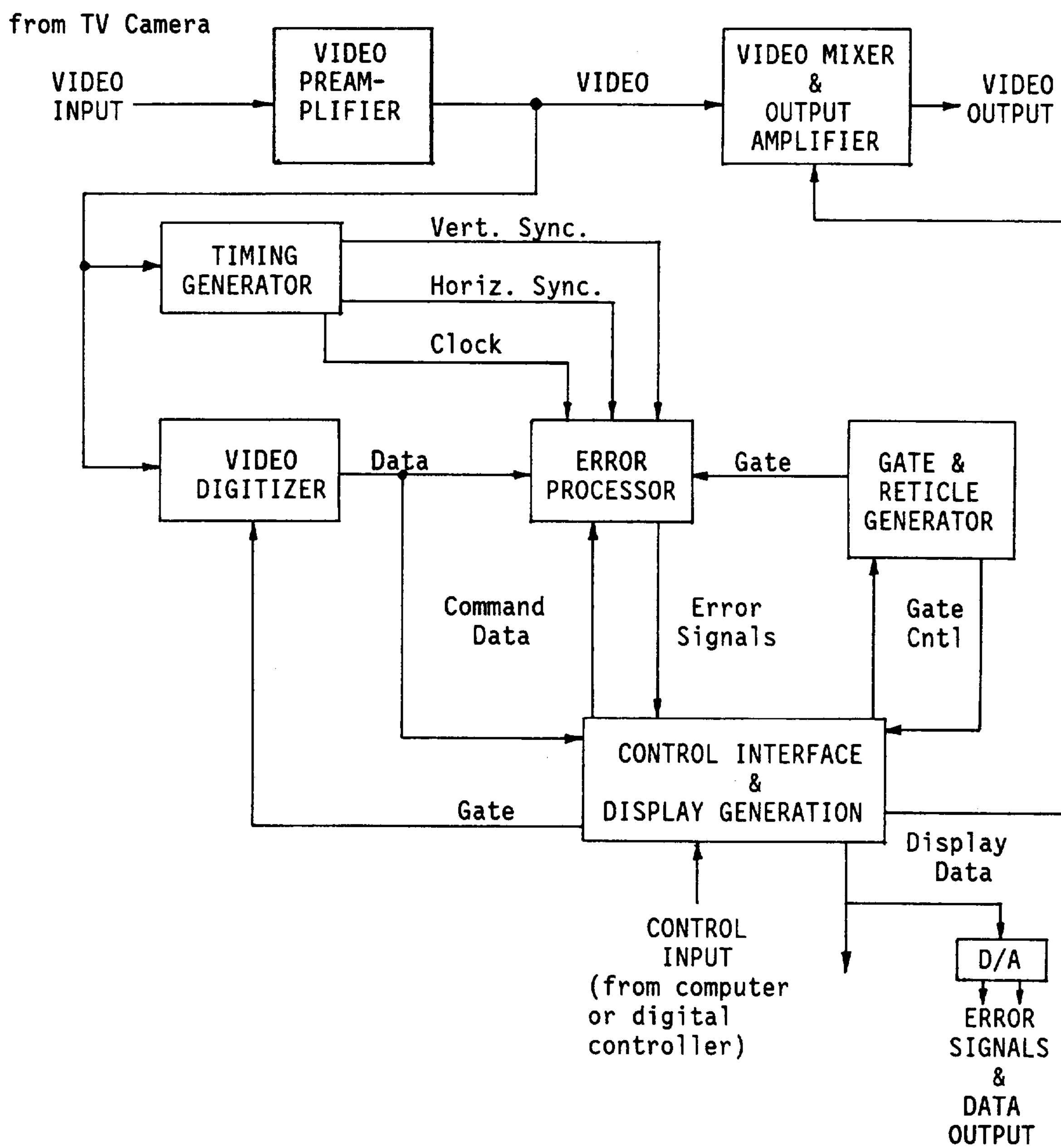

FIGURE 4 - VIDEO TRACKER BLOCK DIAGRAM

mirror position during the target acquisition phase. During this phase the video tracker's outputs are ignored by the microcomputer. Once the target has been acquired, the joystick is disabled and input is accepted from the video tracker, closing the control loop. A block diagram of the complete targeting system is shown in Figure 5. The microcomputer would also be used in the active focussing system.

Target Acquisition and Tracking

The operation of the LIOS system will be based on the following sequence of events. In the target acquisition phase, the operator locates the position on the oil pool at which the lasers are to be aimed and points the lasers at that particular spot. Since there is probably very little image contrast in the infrared prior to laser heating, a video camera is used for this task. This camera can be placed near the infrared scanner, with a dichroic beam splitter directing visible wavelengths to the camera and allowing the infrared to pass through to the scanner. The camera can be connected to the video tracker, which allows the tracking crosshairs to be superimposed on the visible image of the scene. Using the joystick controls, the operator positions the targeting mirror so that a selected point on the oil pool is centered within the field of view. The optical system is adjusted to focus the lasers, which are then turned on. An infrared image of the laser-illuminated spot appears within a second and can be used for tracking purposes.

At this point, the operator can continue to hold the lasers on target with the joystick or he can switch in the video tracker for automatic tracking. Motion of the helicopter results in a displacement of the optical field of view, and hence a displacement of the infrared image of the heated spot. Since the heated spot requires a finite amount of time to cool, it provides a thermal signature of long enough duration to allow the repositioning of the targeting mirror so that the hot spot is maintained to the center of the scene. This adjustment procedure continues until ignition of the oil is confirmed by the operator.

The LIOS system will be operated only while the helicopter is hovering to facilitate the task of keeping the laser beams on target. Using a radar altimeter for feedback, an experienced pilot can be expected to maintain a large helicopter at a desired altitude within ±1 foot for up to a minute under normal flying conditions. The helicopter motion has a low frequency, typically less than 1 Hz, and can easily be compensated by the pointing system.

Vibration Isolation

A factor that can degrade the performance of the LIOS system is the helicopter's internal vibration, especially at the blade rotation frequency[6]. This causes jitter in the optical image, which can cause the targeting system to lose the target. Jitter is reduced by incorporating a passive vibration isolation system comprised of a

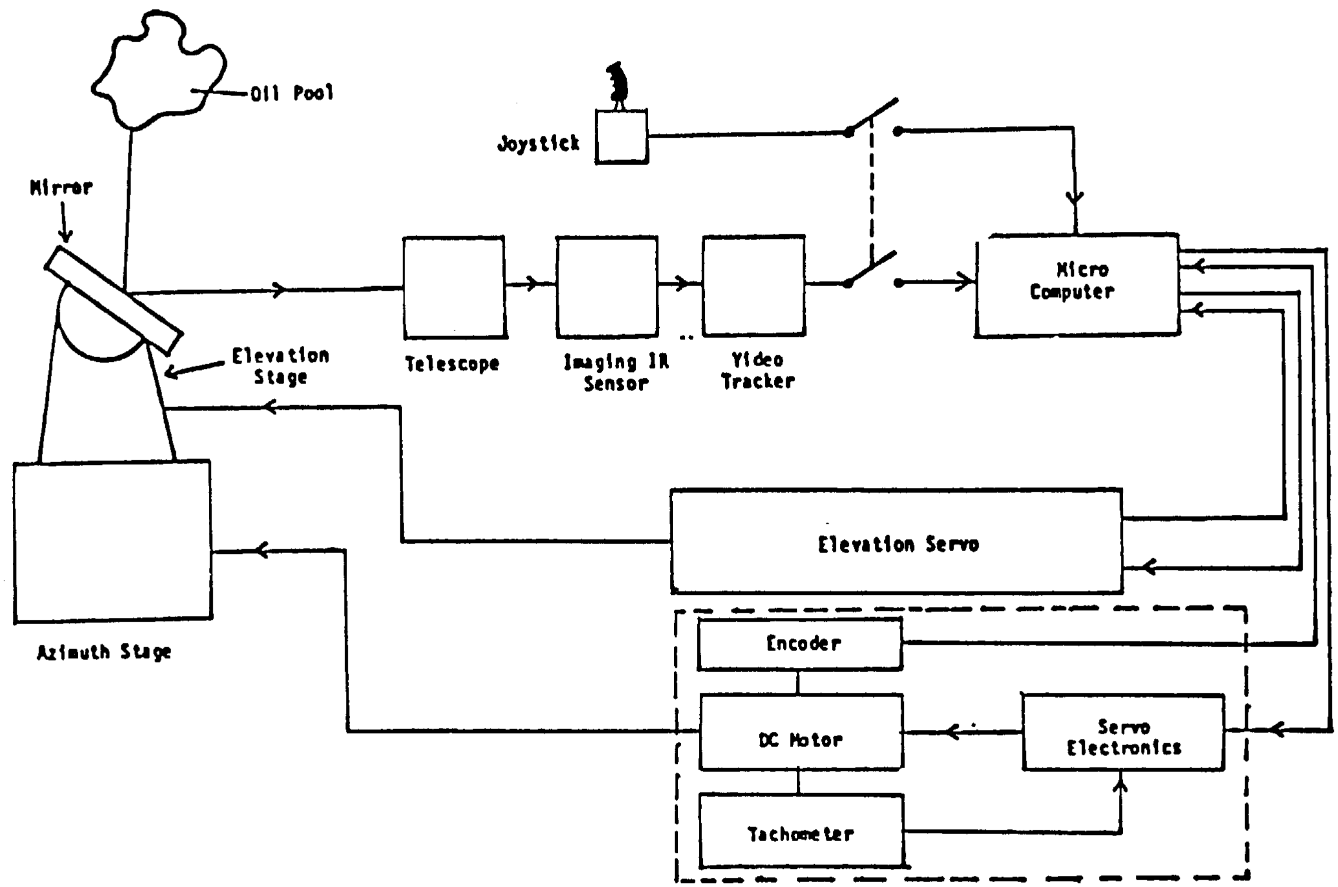

FIGURE 5 - BLOCK DIAGRAM OF L.I.O.S. TARGETING SYSTEM

number of damped springs between the optical support structure and the helicopter cabin. For example, the Sikorsky S-61 has five blades and a rotor speed of just over 3 Hz, resulting in a blade passage frequency of about 15 Hz. Thus the isolation system is designed to have a resonant frequency below 10 Hz and to attenuate at least 90% of the vibration at 15 Hz and above. Viscoelastic-spring dampers such as the Barry H64 mounts meet these specifications although their load capability is not high. Companies such as Barry Controls and Taylor Devices have the capability to custom design an isolation system to these specifications. In addition, the optical components and support structure are designed so that their resonant frequencies are much higher than the blade rotation frequency.

HELICOPTER INSTALLATION

The primary choice of helicopter for the LIOS installation is the Sikorsky S-61, chosen for its large cabin, payload capability, and availability. Although any variant of the S-61 would satisfy the demands of this installation, the HH-3F Pelicans (S-61R) of the U.S. Coast Guard became the likely choice due to their availability at this time. The S-61R features an approximately rectangular floor layout, with a length of 25 feet and a width of 6.5 feet. A 4 foot wide sliding door is located on the right side of the cabin, immediately behind the cockpit. The remaining exit is the large ramp cargo door in the rear of the helicopter. A possible layout of the LIOS system is shown in Figure 6.

Cabin Layout

As can be seen in Figure 6 the cabin of the S-61R is more than large enough for such an installation. The primary drawback in using this helicopter is the small width of the cabin door, as compared to a Bell 212 Twin Huey, for example. The width of 49" is marginally sufficient for the layout, but a wider door would be preferable. Installation of an APU and generator will be required to supply power to the CW laser, and the large cabin space in this helicopter allows for that installation with little difficulty.

One of the major requirements that had to be satisfied in this installation is the one of maintaining access to the available exits. With the 18" wide aisle between the laser installation and the cabin wall, this requirement is satisfied. The laser and flight crews are considered to be trained personnel, who are thoroughly familiar with the layout of the cabin, and its safety features. Although there are no emergency exits as such, the trained crews will not have any difficulty in evacuating the cabin in an emergency through the use of either the rear loading door, or the personnel door in the front of the cabin.

The cabin floor is rated for loads of 200 lb/ft^2, which is more than adequate for this installation. The optical table, focussing

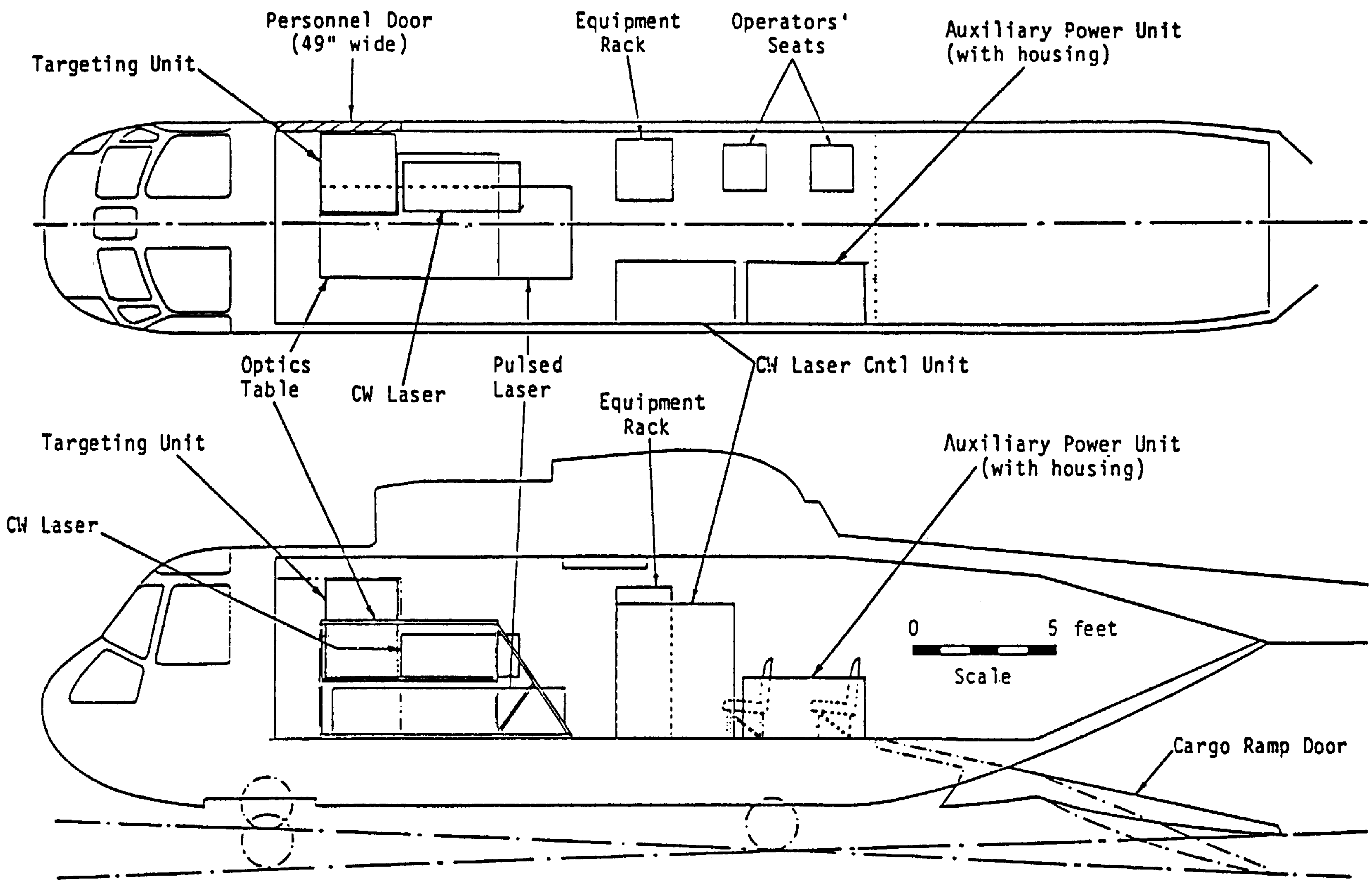

FIGURE 6 - HELICOPTER LAYOUT OF L.I.O.S. SYSTEM

optics, targeting mirror and drive, lasers, and support structure weigh about 1500 lbs. A configurational drawing of this assembly is shown in Figure 7. This assembly will be mounted on Brownline seat tracks as will the equipment rack containing the control electronics. The loaded rack is expected to weigh about 150 to 200 lbs. For ease of integration, all equipment will be packaged prior to installation in the helicopter. Structural frames will be of welded 6061-T6 aluminum construction. The laser consoles together weigh nearly 700 lbs and are situated to one side. The heat exchangers will be mounted on a separate rack and ducting will be provided to ensure a supply of cool air. Finally, the APU and generator will be installed with protective housings.

CONCLUSION

A configurational engineering design for a helicopter-based dual-laser system for igniting oil spills has been completed. The system is to be operated by trained aircraft technicians while the helicopter is hovering at an altitude of 20 m. The system incorporates a Falcon 800 CW CO_2 laser for preheating the oil and a Lumonics TEA-103 pulsed CO_2 laser for ignition. The CW laser is water-cooled using a closed system of three Lytron heat exchangers mounted in the helicopter.

An optical system incorporating a reverse Cassegrainian telescope has been designed for focussing the laser beams. Passive and active methods have been described for controlling the focussing system. The former uses a focus analyzer similar to those found in commercial zoom lens while the latter has a laser range finder. The focussing system is capable of focussing the laser beams over a range of 20 to 30 m.

The laser beams are steered and kept on target by a large mirror mounted on a two-axis mount controlled by an infrared video tracker. The tracking system uses an infrared scanning radiometer to produce a television image of the laser-heated oil spot. This image is processed by a video tracker operating in the centroid mode to generate error signals proportional to the displacement of this spot from the center of the field of view. The error voltages are amplified to drive the biaxial mirror mount. In the prototype system the video tracker can be replaced by a human operator controlling a joystick.

An auxiliary power unit must be installed on the helicopter to satisfy the power requirements of the CW laser. The helicopter installation and configurational layout of the LIOS system and the APU are now specified with costs, sizes, and weights of all system components currently identified.

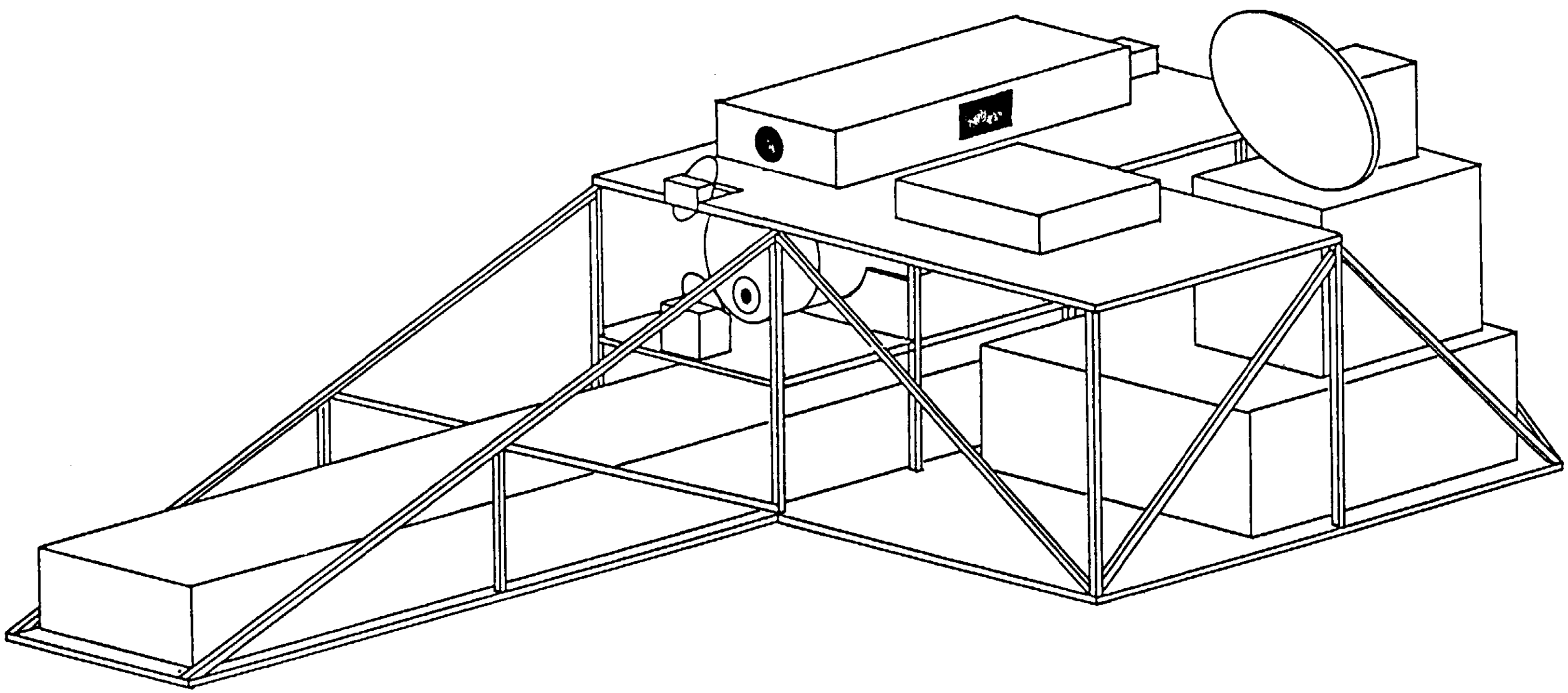

FIGURE 7 - CONFIGURATIONAL DRAWING OF L.I.O.S. SYSTEM ASSEMBLY

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