# THERMAL BLOOMING OF HIGH POWER LASER BEAMS

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Abstract.- With a view to better predicting the effects of thermal defocusing within the atmosphere, an experimental simulation set-up has been designed at ONERA. This consists essentially of a vertical airtight cell containing a gas or gas mixture sufficiently absorbing to induce "blooming" of a $CO_2$ laser beam over a distance of about 3 m.
A return wind tunnel, integrated within the cell, creates a uniform wind on the beam propagation path; the wind velocity may be precisely adjusted between 0.1 and 2 m/sec.
A rotating drum photometric analyser, associated with a data acquisition and processing unit, provides an automatic sequential exploration of the irradiance model observed at the beam focus.
Some characteristic results are presented to illustrate the possibilities offered by the set-up.

1. Introduction - Propagation of light beams through the atmosphere is accompanied by an energy loss by molecular absorption and by scattering on aerosols and molecules. For hight power lasers, the air heating due to absorption induces along the propagation path a reduction of refraction index in the beam axis, whose effect is to spread the beam and to noticeably reduce irradiance relative to its expected value : it is the "thermal blooming" phenomenon, which has been, for over then years, the subject of much theoretical and experimental work [1,2].

To analyse the effects of thermal blooming, computing models and codes have been established by various authors. The experimental verification of the results of these calculations in free field over long paths presents great difficulties in view of the lack of precision in our knowledge of the various physical parameters involved in this phenomenon.

That is why, in order to verify some computing models developed at CGE (Compagnie Générale d'Electricité), a gas simulation cell has been realized by ONERA, with the financial support of DRET (the Research Directorate of the French Ministry of Defence).

This experimental set-up should also be used to evaluate the possibilities offered by phase correcting systems with adaptive optics, intended for compensating thermal blooming effects.

2. Description of the simulation cell - The simulation cell, whose basic design is represented on figure 1, is made of a vertical cylindrical body, 2 m in diameter, inserted between two quasi hemispheric caps ends. The overall height of the tank is 5.20 m. The lower bottom comprises an 0.60 -m-diam. central part, holding the focusing system of the laser beam. This system includes a ZnSe lens of 3.16 m focal length and a window, also in ZnSe, ensuring airtightness. The useful diameter is 50 mm. The laser is focused on a rotating drum beam analyser installed in the upper part, and adjustable between 3 m and 2.40 m from the window. This analyser provides in quasi real time the

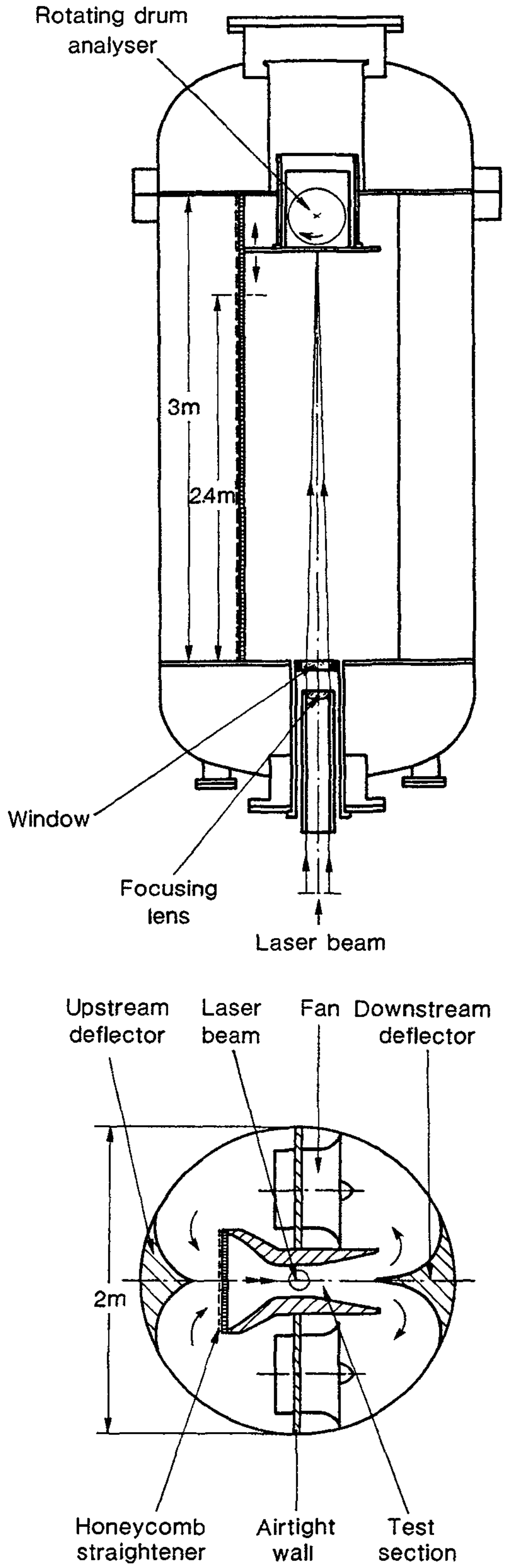


Fig. 1 : Simulation cell.

distribution of irradiation energy in the analysed section of the beam. The absorbing gas, usually $CO_2$, is set in motion by an internal mini wind tunnel, the structure of which can be seen on the cross section of the cell. This wind tunnel is made of two contoured vertical walls occupying the whole height of the cylindrical body (3 m).

The test section, where the beam propagates, is 0.20 m wide; it is preceded by an upstream collector with a contraction ratio of 3, and followed by a short diffuser of 14° apex angle. Gas circulation is ensured by two fans installed through an airtight wall in the median section of the body. To ensure flow uniformity in the test section, a filtering medium is distributed over the honeycomb straightener mounted at the collector inlet. This arrangement makes it possible to obtain a quasi horizontal flow within the testing volume, with a velocity constant to within $\pm$ 5% over the test section height. A guard plate, solid with the analyser, ensures the continuity of the flow at the drum level.

The fans are driven by two hydraulic motors of a power of 4 kW each, at the maximum speed of 800 r.p.m. The motors are supplied by a pumping unit control, located under the cell. Adjustment of the rotating speed is continuously ensured, between 30 and 800 r.p.m., to within $\pm$ 1 r.p.m., allowing a precise variation of the wind velocity between 0.1 and 2 m/sec. The velocity calibration has been realized by means of an anemometric paddle-wheel, and its uniformity checked with a hot wire probe.

Pressurization circuits ensure the evacuation of the cell, its filling with air or $CO_2$

between 0 and 15 bars and its draining to atmosphere; filling with an air-$CO_2$ mixture is also possible.

A control console, located in the measuring room, ensures the following functions : pressurization control, pumping unit control, measurement of physical parameters of the gas in the cell : pressure, temperature and wind velocity.

3. General description of the experimental set-up - The general layout of the set-up is presented on figure 2. At the lower level of the cell are located : the $CO_2$ laser, whose power may be adjusted between 0 and 400 W, an HeNe laser for alignment, a removable checking calorimeter, an afocal optical system whose magnification may be changed at will for modifying the transverse dimension of the beam entering the cell, hence the characteristic value of the Fresnel parameter. A molybdenum mirror set at 45° turns the beam vertical towards the cell.

The cell checking devices for pressurization, measurement of physical parameters of the gas, as well as the data acquisition and processing unit, are put together in an independent measuring room.

4. Beam analyser - This analyser, fabricated by ETCA (Central Technical Establishment for Armament , French Ministry of Defence), is made of a 35-cm-dia. drum, rotating at 600 r.p.m. One hundred 0.3-mm-dia. holes are distributed over its periphery, and spaced over a height of 20 mm. A window in the instrument casing gives to the laser beam access to the drum, and fixes the boundaries of the rectangular analysis frame : 20 x 11 mm.

At each turn, the beam section is sequentially explored over the height of the window. A pyroelectric detector, integrated

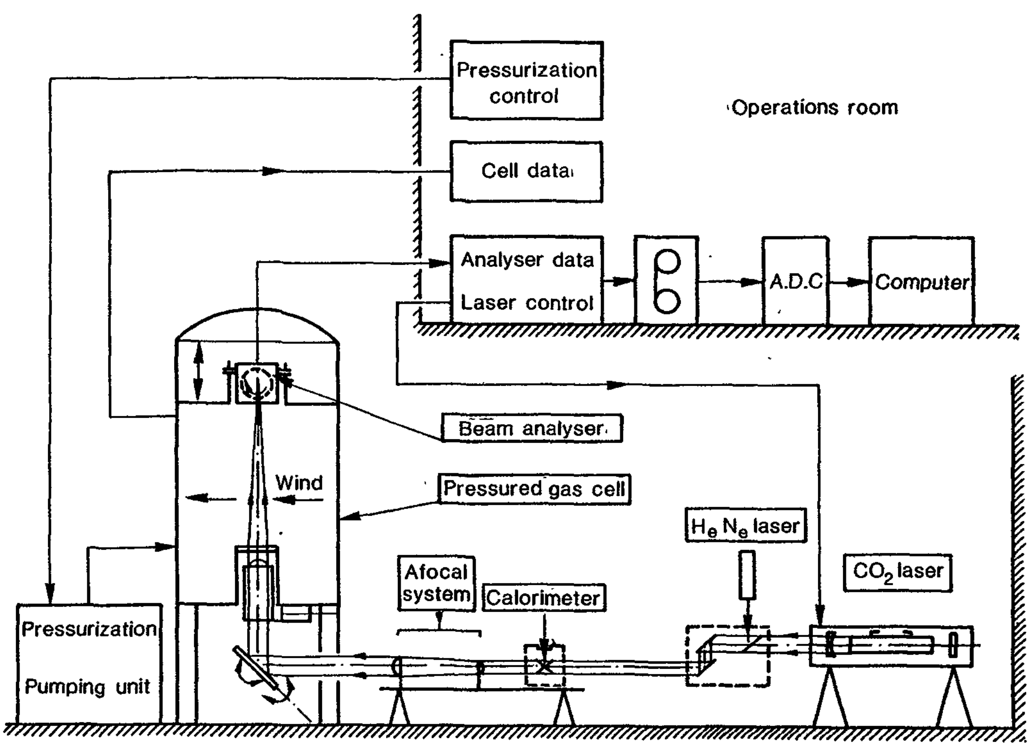


Fig. 2 : Experimental set-up.

within the instrument, receives successively the flux which has crossed each hole of the drum, and thus gives rise to a succession of analysis signals similar to television video signals. Complementary holes, associated with optical couplers, deliver an electric pulse of line synchronization at the passage of each analysis hole, and a pulse of frame synchronization at each turn of the drum.

5. Data acquisition and processing - In the initial concept of the measuring unit, acquisition of the electric signals issued from the analyser is ensured in two steps : analog magnetic recording at the rate of 152 cm/sec., then digitization on the magnetic tape of an H.P. 21 MX computer by reading of the analog recording at the reduced rate of 38 cm/sec.

This operating procedure was chosen with a view to ensure compatibility between the sampling frequency related to the time resolving power of the analyser (55 kHz) and the digitization frequency imposed by the present analog-to-digital converter. A faster converter will allow, at a later stage, the suppression of the analog recorder.

Before being recorded, the signals are received on the analyser control unit, which ensures the following functions : generation of 55 pulses per line, for digitization of the video signal, "zero recovery" for compensating the drift of the video signal related to the capacitive effect of the pyroelectric detector.

Before digitization, the recorded analog signals are directed towards an adaptation unit ensuring the selection of the sequence to be digitized; this selection is performed by predetermining on two counters, the ranks of initial frame and final frame of the sequence. A "control gate", triggered by the counters, selects the digitization pulses that are sent, together with the video signal, to the analog-to-digital converter of the computer.

The digital data stored on magnetic tape are then processed by means of codes recorded on disc. The main code provides a digital representation, by stitches, of the irradiation distribution observed in the analysis window; the information, displayed on a screen or printed, is restituted frame by frame or calculated as mean values over a predetermined set of frames.

Other codes are also available : graphic representation of lines of equal intensity, three-dimensional representation by perspective effects, plotting of curves representing, as a function if the experimental parameters (laser power, wind velocity), the evolution of some characteristic results : maximum irradiation, mean irradiation within a circle centered on the bary centre and containing 63% of the energy, radius of this circle, etc...

6. Results obtained - Figure 3 is an example of three-dimensional representation obtained in the case of relatively important blooming.

On figure 4 are compared, for identical operating conditions, the results provided by the CGE computing code and the experimental distributions observed in maintaining constant the ratio of laser power by wind velocity; these latter results seem to prove that blooming does not only depend on the P/V ratio, but tends to increase when P and V increase together.

Figure 5 represents the evolution of the maximum intensity as a function of laser power for various wind velocities.

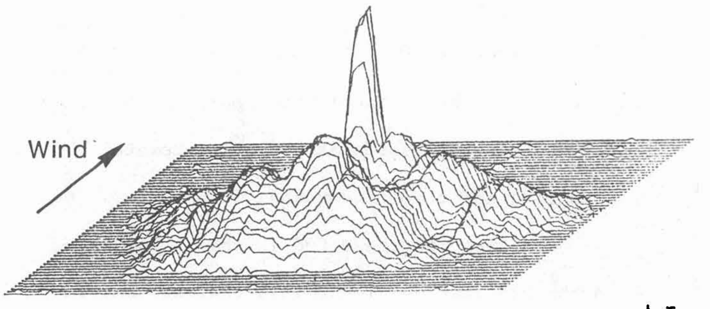


Fig. 3 : Three-dimensional representation of irradiance.

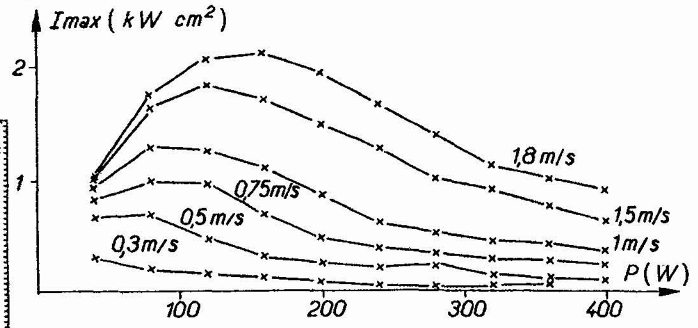


Fig. 5 : Defocusing curves obtained for various values of the wind velocity (Fresnel number $N_F$ = 10)

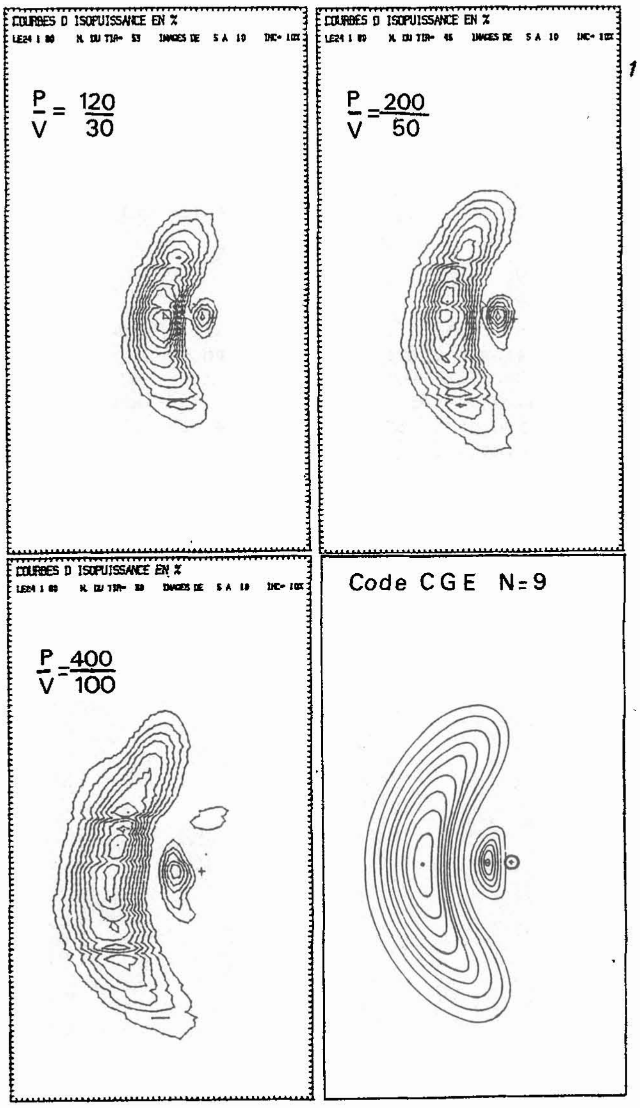


Fig. 4 : Comparison with the result of the CGE code of models observed at P/V = 4 (N = 9) for various values of laser power and wind velocity

P : power, in W
V : velocity, in cm/sec.

For the moment it is not possible to draw a significant conclusion on the comparaison of the absolute energy levels provided by experimental means and computing codes, because of delays in the running of the planned experimentation, due to technological difficulties, and of one insufficiently precise knowledge of some characteristic elements (beam size at the cell inlet, quality factor).

7. Project of experimentation of corrective systems with adaptive optics - A complementary experimentation on this set-up is planned, it aims at studying the behaviour of corrective systems with adapted optics in the presence of thermal blooming.

The first system is a multidither C.O.A.T. mirror, constructed by the Ecole Polytechnique Laboratory. This mirror comprises 21 elements 40 mm wide, controlled in translation by piezoelectric ceramics. Each mirror is mounted on a knee-joint allowing a precise orientation adjustment and the periodic correction of long-term shifts inherent to piezoelectric supports.

The second device is a single plane mirror, built by ONERA (POLA), intended for an experiment of automatic pointing on aerial targets; this fine pointing system, mobile along two orthogonal directions, provides a conical spatial exploration within a 1.3 mrad sighting field.

An appropriate optical bench has been realized, allowing the spreading of the beam to the diameter required for adaptive optics, then its reduction for access to the cell.

A second bench, placed above the set-up, will allow simultaneously picking up the information for the mirror servocontrol and using the beam analyser.

8. Conclusion - An experimental simulation cell intended for the study of thermal blooming has been realized at ONERA. This cell, originally conceived as an automatic and operational test set-up, has been associated with elaborate measuring and computing means.

The results presented in this paper show, on the qualitative view point, the real interest offered by this set-up, in spite of some difficulties that retarded the running of the planned experimentation.

New experiments will now be performed, after addition of a second analyser which will allow a more precise characterization of the laser beam entering into the simulation cell.

References

[1] Smith, David C., "High-Power Laser Propagation : Thermal Blooming" Proceedings of the IEEE Vol. 65 N°12, December 1977.

[2] Gebhardt, Frederick G., "High power laser propagation" Applied Optics Vol. 15 N°6, June 1976.