Document:

Technical Specification

Supply of laser systems for PIV, PLIF and Rayleigh Thermometry, for combustion applications

Technical Specification

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1. Premises

This document describes the supply of a diagnostic system ("turnkey") for Co.Svi.G. – Sesta Lab, necessary for the execution of fluorescence and elastic diffusion measurements from laser light in order to investigate combustion processes for gas turbine burners. The goal is the measurement of velocity fields, concentration of chemical species and temperature field.

2. Goal of the supply

Sesta Lab is a 100% public company (Italy), placed in the community of Radicondoli (Siena) at the km 2.7 of the road SP37. Sesta Lab is an important player for the execution of full scale combustion tests on turbogas burners. The most important manufacturers on Oil&Gas, Power Generation and Aviation markets are clients of Sesta Lab.

Sesta Lab has two test benches, weekly rented to the customers.

Thanks to the economic support from the Tuscany Region tender FAR-FAS 2014 (Operative Objective 2, OO2), Sesta Lab has decided to enlarge its business to the pure R&D field, with particular focus on the analysis of combustion processes for turbogas systems, in order to:

- Actively enter in the research world
- Diversify the services for its clients
- Develop diagnostic techniques for turbogas systems

Sesta Lab is going to build a new Test Bench (Test Cell 3, hereinafter), with max performances lower than the current benches (approx. 1.5 kg/s of combustion air @ 600°C, with a max natural gas flow rate of 40 g/s), but fully optimized for the use of hi-tech instrumentation and for optical analyses on combustion. A new Test Rig (optimized for the use of optical techniques) will be developed and placed inside Test Cell 3. Sesta Lab is currently not in charge of the manufacturing of the new Test Rig and does not have any drawing or can share any sketch of the new Test Rig.

The optical techniques currently of interest for Sesta Lab are:

- PIV
- LIF/PLIF
- Time resolved thermography
- Laser thermometry

A preliminary sketch of Test Cell 3 (planimetry) is available and reported in Figure 1. The size of the Test Cell 3 is under approval and can change of approx. 1m less in the directions x, y and z. Figure 1 indicates two possible positions for the Test Rig: Rig (1) is the worst position while Rig (2) replicates the best solution in term of optical path for the laser beams. The Test Rig is currently not available for Sesta Lab. However it will be optimized for the use of optical techniques on combustion analyses for turbogas. It will be equipped with at least 3 (optimally: 4) quartz/sapphire windows, orthogonal to each other's (not object of the supply). The Supplier has to take into account the Test Rig as a parallelepiped, with a squared test section. The mixture ait/gas will be fed from one side of the Test Rig, while the exhaust gases will be collected in a gas duct downstream the Test Rig and then driven to the chimney. The Test Section will be provided with at least 3 (optimal 4) quartz/sapphire windows, size 100x200 mm^2.

The supply of the laser system will be framed inside the tender "Bando FAR-FAS 2014" (promoted by Regione Toscana) and inside the "Piano Nazionale Industria 4.0" (promoted by Ministero dello Sviluppo Economico). Moreover the supply should be accompanied with certifications/declarations from the supplier which has to prove the characteristics of the supply as compliant to the research uses described in this Technical Specification.

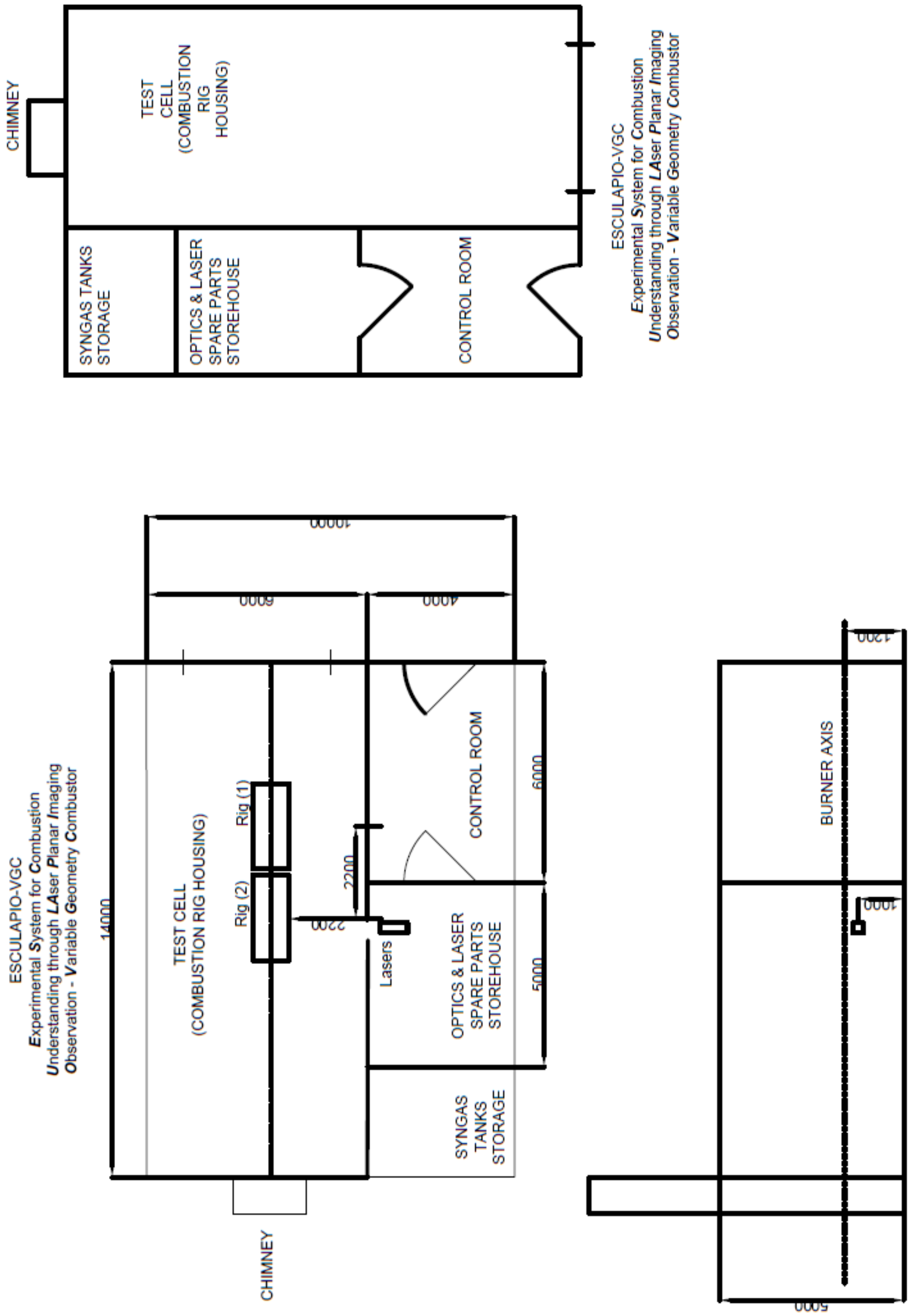


Figure 1: Sketch of Test Cell 3

Sesta Lab specifies that the Test Cell 3 sketch reported in Figure 1 is purely illustrative and that the access point of the light sources to the Test Area could be changed, accordingly with the optical techniques used and in order to optimize the optical paths. Suggestions and proposals from the suppliers will be evaluated.

On these basis, Sesta Lab requires the supply of two laser systems, PIV and PLIF/Rayleigh Thermometry, respectively, dedicated to the optical analyses of flames and combustion processes for turbogas systems.

3. Description of the supply

The goal f the tender is the supply of two laser systems ("turnkey") for the execution of PIV (Particle Image Velocimetry) and LIF (Planar Laser Induced Fluorescence) measurements on turbogas systems. The PLIF system will have to allow also Rayleigh Thermometry measurements. Both the laser systems will be placed inside Test Cell 3. The laser systems will be stored in an air conditioned room, with temperature and humidity control and with a partial air filtering system. The room will be provided with a direct access to Test Cell and consequently to the Test Rig. Test Cell 3 will not be air-conditioned. Sesta Lab does not have data about the mechanical and sound vibrations expected inside Test Cell 3. Test Cell 3 will be placed inside Sesta Lab, in an environment subjected to H_2S.

The supply of complete and "turnkey" systems is necessary to avoid all the possible risks derived by the assembly of the systems by Sesta Lab technicians (not currently specialized in the handling of laser systems). Moreover Sesta Lab expects a high post sell customer's assistance by the supplier. The supply of complete and "turnkey" systems is unavoidable for the participants to the tender and is a binding point for the assignment of the tender.

The supply of the systems have to be completed by 14 weeks from the finalization of the tender.

a. PIV system

Sesta Lab requires the supply of a laser system in order to perform velocity fields measurements with PIV technique. The system has to be able to perform also PIV/PIV-stereo measurements.

The system must include all the necessary to perform PIV measurements with a sampling frequency of 5 kHz. The system will include the laser source, an optical system for the delivery and shaping of the laser beam, cameras (fast Ethernet, with on-board memory) complete with lenses and objectives, all the hardware necessary for the digitalization of the sampled images with a codification at least 12 bit for pixel, the acquisition and post-processing software (aligned with the current state of art for PIV technique), a seeding system usable also with reactive (e.g. combustion) processes (optional).

The technical specifications of the components for the PIV system are listed in the following. The list has been internally evaluated by Sesta Lab technicians and considering reasonable configurations (i.e. Test Rig position and laser path). However, changes in the proposed configuration are possible (if not compromising the final goal of a PIV system and the minimum required technical specifications) and have to be submitted to Co.Svi.G. Sesta Lab for approval.

The laser source (complete of cables, cooling system and all the necessary for its usage), Nd:Yag or Nd:YLF, double cavity, has to provide an output at 532 nm or 527 nm or anyway in the visible side of the light, with energy of at least 5mJ/pulse at 5kHz. The laser source must operate until 1 kHz, with an energy not lower than 13mJ/pulse. The energy rms value of the output beam has to be lower than 1%, while the maximum divergence has to be lower than 10mrad. The supply of a laser source able to provide higher energy/pulse at 1kHz and 5kHz will be considered as a plus.

In order to ensure proper temporal delays between consecutive laser pulses, the supply of a time compensation system between the laser pulses and the trigger Q-switch signal is required. The compensation system shall ensure a 10% maximum time difference between the laser pulses and the Q-switch trigger signal. The compensation system must be mechanically adaptable to the laser source.

The laser sheet will be created by using convergent/divergent/cylindrical lenses systems or telescopic objectives (included in the supply) and will be driven to the Test Section. For PIV measurements the laser sheet will light the seeding particles, which will scatter the laser light. The light signals from the Test Section will be acquired by two CMOS cameras, able to operate at a frequency of at least 5 kHz, full frame. The operator must have the possibility to change the acquisition frequency, both for higher and for lower values. The minimum resolution has to be 1280x800 pixel (1MP) at 5 kHz. The supply of cameras with higher resolutions (1600 x 1200 pixel – 2 MP – or equal or higher than 2048 x 1536 – 3 MP -) will be a plus. Sesta Lab requires the possibility to change the acquisition frequency to higher values. In this case, a reduction of resolution could be acceptable. Sesta Lab requires the possibility to change both the frame length and the frame height, independently. The images have to be at least 12bit deep. The supply of cameras with an acquisition higher than 12bit will be a plus. Each camera have to record videos/images in an internal memory board not less than 64GB. The camera will be placed on mechanical supports, with manual regulation systems, included Scheimpflug regulation systems for stereo-PIV measurements, with an accuracy inside 1mm in the directions x, y, z. The supply of motorized Scheimpflug system (controlled by software) will be evaluated as a plus.

The communication between the cameras and the acquisition system will be through an Ethernet cable (fast Ethernet). All the necessary cables and whatever not explicitly described in this paragraph, but necessary for the right integration of the cameras with the acquisition system is part of the supply.

Each camera will come with an objective with focal length included between f = 85mm and f = 105mm, at least F/2.8, manual, F-Nikon bayonet. The objective must couple with the cameras. The supply of objectives f = 200mm, at least F/2.8 in addition to the previous objectives will be evaluated as a plus. Sesta Lab recommends the supply of objective with vignetting less than 0.7EV, fully open.

Sesta Lab requires the supply of two green filters (for the cameras), with characteristics 532nm +/- 10nm. In case of supply of lasers with 527nm output, the green filters will be 527nm +/- 10nm

Sesta Lab requires the supply of a PIV calibration kit. It will be a 50x50 mm^2 plate with dot marks (1.5mm each), with a pitch of 5mm.

The supplier will also supply two peak locking filters, dedicated to the reduction of peak locking errors and uncertainties. The peak locking system must be compatible with the supplied hardware and with the Scheimpflug regulation system.

Moreover Sesta Lab requires a seeding system for the injection of the seeding particles in the Test Section. The seeding system must have a design pressure not lower than 15 bar and have to work in the range [1 – 15] bar, with a minimum air flow rate of 0.25 kg/s. The supply of a seeding system designed up to 600°C will be evaluated as a plus. The control system and everything upstream the injection system is not interested for the supply.

Sesta Lab requires 5 kg of TiO_2 and Al_2O_3 seeding particles, with diameter included between 0.5 e 4 μm.

Sesta Lab richiede inoltre la fornitura di un sistema inseminante per l'iniezione di particelle all'interno della sezione di prova. Sesta Lab richiede un sistema inseminante certificato per pressioni non inferiori a 15 bar ed esercibile nel range [1 – 15] bar, con portata minima di aria pari a 0.25 kg/s. La fornitura di un sistema inseminante capace di gestire portate d'aria a temperatura di 600°C sarà valutato come un plus opzionale. Non è oggetto della fornitura il sistema di controllo, e quanto fisicamente a monte del sistema di iniezione.

Sesta Lab richiede inoltre la fornitura di 5 kg di particelle di biossido di titanio TiO_2 e 5 kg di ossido di alluminio Al_2O_3. In entrambi i casi le particelle dovranno avere diametro medio compreso tra 0.5 e 4 μm.

b. PLIF/Rayleigh Thermometry system

Sesta Lab requires the supply of a laser system in order to perform PLIF and Rayleigh Thermometry measurements. Performing simultaneous 2D thermometry and radical OH-PLIF detection on turbogas flames is final the goal. Concerning the planar thermometry, Sesta Lab requires a laser system based on Rayleigh scattering simultaneously working with the fluorescence (PLIF) laser.

The systems shall include all the necessary equipment needed for the execution of the OH-PLIF measurements and 2D thermometry with a sampling frequency of at least 10 Hz. The system will include the laser sources (pump laser + dye laser), an optical UV lenses system transparent for the delivery of the beams, convergent/divergent/cylindrical/telescopic objective UV transparent for the laser sheet shaping, cameras (fast Ethernet, with on board memory) complete with UV lenses, all the necessary hardware for the acquisition of 12bit deep images, an acquisition and post-processing software able to manage with PLIF, Rayleigh and PIV measurements.

In the following, the components necessary for the execution of 2D OH-PLIF and thermometry measurements is done. The list has been internally evaluated by Sesta Lab technicians and considering reasonable configurations (i.e. Test Rig position and laser path). However, changes in the proposed configuration are possible (if not compromising the final goal of a PIV system and the minimum required technical specifications) and have to be submitted to Co.Svi.G. Sesta Lab for approval.

The laser source (complete with cables, cooling and all the necessary for its use), Nd:Yag (pump laser), will have to provide a 532nm output at least at 10Hz repetition frequency and with a time duration of no more than 10ns. The laser beam will feed a dye laser, able to provide an output at 283.2nm, with energy of the single pulse at least equal to 20mJ/pulse at 10Hz. The laser beam output from the dye laser will have a divergence included in 1mrad. Laser beams with an energy higher than 20mJ/pulse at 10Hz at 283.2nm will be evaluated as plus, as well as the possibility to reach higher a higher repetition frequency, with an output however not lower to 5mJ/pulse at 20Hz at 283.2nm. The supplier has to indicate also the dye for the dye laser and for the execution of OH radical measurements.

The supplier has to describe all the maintenance action for the dye laser as well as the actions to do for the recharge of the dye. Sesta Lab asks the supply of at least two dye recharge.

In order to use the pump laser also for Rayleigh Thermometry measurements, Sesta Lab requires an output for the pump laser not less than 400mJ/pulse at 10Hz at 532nm, or (evaluated as a plus) an output not less than 120mJ/pulse at 10Hz at 355nm. The output from the pump laser must have an energy rms below 1% and a maximum divergence included in 5mrad.

The laser source will be provided with a shutter (controlled with the software), which will be able to close the laser port for small times, usually necessary to provide quick minor changes and adjustments to the experimental setup.

Sesta Lab requires an energy monitoring system in order to monitor the lasers energy output. The operator will have the possibility to compare the measured output with the desired energy values. Sesta Lab will accept the supply of the monitoring system only in the case the loss of energy for the laser beams through the monitoring system is less than 5%.

The laser beam output from the dye laser will be delivered and shaped in a sheet using convergent/divergent/cylindrical lenses or telescopic objectives, UV transparent. The laser sheet will be delivered to the Test Section by passing through a beam splitter in order to separate the light depending on the wavelength (light for dye laser pumping and light for Rayleigh Thermometry).

The light signals coming from the Test Section will be acquired by two CMOS cameras, with an image intensifier each (removable intensifiers). One camera will be dedicated to the OH fluorescence signal, while the other will acquire signals for Rayleigh Thermometry. Both the cameras will have a polarized filter and will have small exposure time (less than 100ns, tunable). The minimum resolution has to be 1280x800 pixel (1MP).The supply of cameras with higher resolutions (1600 x 1200 pixel – 2 MP – or equal or higher than 2048 x 1536 – 3 MP -) will be evaluated as a plus. The sampling frequency must be tunable and not less than 30Hz, full frame. Sesta Lab requires the possibility to change the sampling frequency to higher values. In this case, a reduction of resolution could be acceptable. Sesta Lab requires the possibility to change both the frame length and the frame height, independently. The images have to be at least 12bit deep. The supply of cameras with an acquisition higher than 12bit will be a plus. Each camera have to record videos/images in an internal memory board, recommended not less than 16GB. The camera has to be placed on mechanical supports, with the camera position manually regulated. The communication between the cameras and the acquisition system will be through an ethernet cable (fast Ethernet). All the necessary cables and whatever not explicitly described in this paragraph, but necessary for the right integration of the cameras with the acquisition system is part of the supply.

Each camera will come with an objective UV transparent with focal length included between f = 85mm and f = 105mm, at least F/2.8, manual, F-Nikon bayonet. The objective must couple with the cameras. The supply of objectives f = 200mm, at least F/2.8, UV transparent in addition to the previous objectives will be evaluated as a plus. Sesta Lab recommends the supply of objective with vignetting less than 0.7EV, fully open. The supplier has to submit a technical sheet/document which can provide the proof of the usage of the objectives in the UV.

Sesta Lab requires the supply of two image intensifiers, to be coupled with the supplied cameras. The intensifiers are necessary in order to properly acquire the OH fluorescence signals (peak on 310nm) and for a better acquisition of the Rayleigh scattering for Rayleigh Thermometry, usually very weak. The intensifier must have a QE (quantum efficiency) at least equal to 15% in the range [200 – 450]nm and still have a reasonable sensitivity until the near infrared (800nm). The intensifiers must be "pulsed type", with a minimum exposure time not more than 10ns. The intensifiers have to couple smoothly with the cameras and the objectives.

Sesta Lab requires the supply of a UV (for the cameras), with characteristics 320nm and a FWHM +/- 20nm. Sesta Lab asks for the transmission certificate for the filters, which must be not less than 70% in correspondence of the nominal wavelength (320nm).

Sesta Lab requires the supply of a UV filter (for the cameras), with characteristics 266nm and a FWHM +/- 10nm. Sesta Lab asks for the transmission certificate for the filters, which must be not less than 60% in correspondence of the nominal wavelength (266nm).

Sesta Lab requires the supply of a UV filter (for the cameras), with characteristics 355nm and a FWHM +/- 5nm, for Rayleigh Thermometry measurements. Sesta Lab asks for the transmission certificate for the filters, which must be not less than 80% in correspondence of the nominal wavelength (355nm).

Sesta Lab requires, as a plus for highly recommended, the supply of a system (included all components and lenses) for the minimization of the stray-light effects in order to optimize Rayleigh Thermometry measurements. Summarizing, techniques which allow structured lighting could be adopted. The system must be automatized and have to optimize the Rayleigh signal, with a reduction of the background noise, by properly modulating the laser signal. So, the system have to allow the separation of the modulated laser signal from the not modulated laser signal. In case of supply of the system for structured light shaping, Sesta Lab requires the delivery of a system of rails, lenses holders, cylindrical lenses/telescopic objectives, prisms or Ronchi gratings and/or everything necessary for the shaping of the structured laser sheet.

c. Parts in common for PIV and PLIF/Rayleigh Thermometry systems

In the following the components in common between the two laser systems (PIV and PLIF/Rayleigh Thermometry) are described.

Both the laser sources have to be placed on an optical table. Sesta Lab, also in consideration of the of the aggressive environment present in Sesta Lab, requires an optical table with aluminium top. The table must have size not less than 1500mmx1800mmx200mm. The supplier can propose a different optical table, which has to be approved by Co.Svi.G. Sesta Lab.

All the components necessary for the delivery of the laser signals from the laser sources to the Test Section, both for PIV and for PLIF/Rayleigh Thermometry measurements must be included in the supply. The supplier can refer to Figure 1 for the position of the Test Rig and for the planimetry of Test Cell 3. The supplier can propose alternative solutions in terms of laser passages and laser disposition. The alternative solution must be submitted for approval to Co.Svi.G. Sesta Lab.

In the following, it is described a list (exemplificative, but not exhaustive) of necessary components in common by the two laser systems:

- Low absorbance lenses (for the wavelengths of the laser sources), with the necessary supports and systems to drive the beams to the Test Section. For PLIF/Rayleigh Thermometry measurements it must be considered the use of lenses appropriate for high energy UV light.
- A system of rails and mechanical structures necessary for the delivery and the transport of the laser beams. The supply of the mechanical structures (with a dedicated project) is optional and will be evaluated as a plus. However, the supplier must submit a detailed layout to Sesta Lab, for approval.
- A shaping system in order to create the laser sheets, with final length between 50 and 200mm. Sesta Lab requires that even for PIV measurements, the shaping lenses (or telescopic objectives)

have to be UV transparent, since the same optical system could be used to manipulate the sheet for the Rayleigh Thermometry measurements.

The shaping system can be assembled from convergent/divergent/cylindrical lenses or by using telescopic objectives, transparent in the range [200 – 750] nm (with focal lengths -10mm, -20mm e -50mm).

- Tubes, mechanical shields, supports, connections necessary for the realization of a protected path (or more, if convenient for the measurements). These paths have to be cleaned with compressed dry air, in order to avoid filth and over temperature on the lenses.
- An UV transparent beam combiner, in order to light simultaneously the Test Section with the beams coming from both PIV and PLIF laser sources.
- One or more laser dampers, in order to decrease the laser beams energy after the passage through the Test Section. The dampers must be designed to sustain a continuous damp for the described laser sources, full power.

The transport systems for the delivery of the laser beams to the Test Section must have a maximum loss of energy less than 15%. This is particularly true for the PLIF source. The supplier has to give the proof of the maximum attenuation to Sesta Lab.

Sesta Lab requires that both the systems have to be completely independent to each other. Moreover the supplier cannot use a unique laser source, splitting the laser beam with a beam splitter.

The supplier can propose the delivery of the signal from the laser sources to the Test Section by using optical fibers. In this case, Sesta Lab will consider acceptable a maximum decreasing of energy not exceeding 20%. The supplier has to give the proof of the maximum attenuation to Sesta Lab.

The supplier, on the basis of Figure 1, must provide a detailed layout to Sesta Lab, which will include the disposition of lasers on the optical table, the passages for the laser beams, the delivery systems, the shaping systems, until the Test Section. The layout must be approved by Sesta Lab for acceptance. However Sesta Lab underlines that the optimization of the passages and of the laser placements, as well as the structure of the Test Cell is still under design and possible amendments and optimization are still possible, since the goal is the optimization of the optical measurements.

The signals coming from the Test Rig will be acquired by the cameras and then the data will be transferred to the acquisition system through Ethernet ports (fast Ethernet). The system includes one or two PCs (the supplier must motivate the decision. In case of two PCs, one is for PIV and the latter for PLIF acquisitions) dual processors, with core not less than 12 each. The supply will include keyboards, mouses, DVD readers, 32GB RAM each, hard disks (at least 2 TB or equivalent), 24" screens, OS Windows. Sesta Lab requires the implementation of a GPU package in order to increase the speed for PIV images post-processing.

The acquisition, control and post-processing software (the same for both PIV and PLIF/Rayleigh Thermometry) must be a commercial software, with possibility to acquire/export files in format BMP, JPG, TIF, Tecplot, DAT, TXT, PS. The possibility to acquire AVI format videos is also required. The software must do calibration, distortion reduction, image masking, evaluation and correction of the laser attenuation through the mean (eventually with additional packages), vignetting correction, evaluation of fluid dynamics quantities (Velocity, standard deviations, TKE, vorticity, …), concentration profiles, temperature profiles and in general everything necessary for the acquisition and post-processing of PIV, PLIF and Rayleigh Thermometry images. Sesta Lab requires at least two license, each placed in at least 2 PCs (not working at the same time). The software must be usable also for the execution and acquisition of 3D tomographic images. However Sesta Lab does not require the package for 3D tomographic images and this upgrade is delayed to future upgrades.

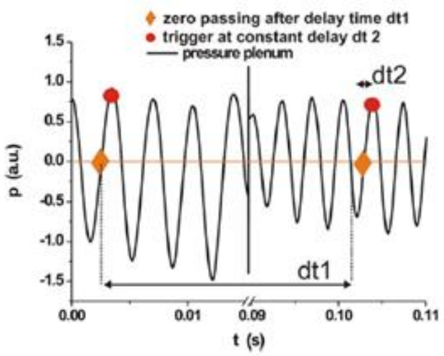
The software must perform control, acquisition and post-processing operations. It has to control simultaneously both the laser sources and the synchronization for PIV + PLIF and PLIF + Rayleigh Thermometry measurements. The software has to have then full control on all the laser sources, including the dye laser. The software must be commercial and the supplier has to be the owner or its official supplier (with official license for the distribution). Outside these two cases, Sesta Lab cannot accept the software (even third party software or open source software). The supply of software specifically developed for this Tender is not allowed.

Sesta Lab requires to receive (for free), new releases of the software eventually released in the next 5 years (which will substitute the old releases). Moreover Sesta Lab asks for life time upgrades for the software packages, until upgraded by the software developer.

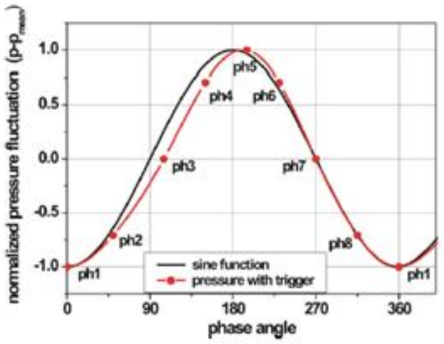
In order to establish a good synchronization of the laser systems, Sesta Lab requires the supply of one or more synchronization systems in order to perform simultaneous PIV and PLIF measurements and PLIF + Rayleigh Thermometry measurements, accordingly with the specifications reported in this document. The choice of the synchronization modules can influence the choice of the number of PCs to supply: the supplier can propose multiple acquisition on the same PC or master/slave configurations with two PCs (for synchronized test).

The proposal must be submitted to Co.Svi.G. for approval, underlining the benefits for the chosen solution.

Sesta Lab requires (as optional and evaluated as a plus) the supply of a synchronization module for the lighting/acquisition based on the frequency of the pressure inside the combustion chamber (measured with proper pressure transducers, not object of the supply described in this document). The synchronization module consists of a triggering that, independently from the frequency of the light sources, triggers the emissions of the laser pulses as synchronized with a time points series belonging to consecutive periods of the harmonics of the acoustic signal sampled with dedicated transducers. Precisely the acoustic wave zero crossing was taken as a triggering signal for a "delay generator" system, capable to inhibit each laser source for a time dt1, equal to the largest integer number of pressure cycles Tp included in the instrument's repetition period. Once passed the main inhibition time dt1, a new change in the pressure signal sign starts up the trigger operation, which commands the wait for a further dt2 delay interval. dt2 is equal to so many sub-intervals of the "acoustic half-period” how much is the “phase” number to which the desired sample must correspond. In other words, at the first dt1 ending, $dt2=(Tp/2)/N_{phases}$ then at the second dt1 ending, $dt2=2\cdot(Tp/2)/N_{phases}$, an so on. Figure 2 is attached for clarity. The supplier can refer to the paper Meier, W., et al, “Detailed characterization of the dynamics of thermoacoustic pulsations in a lean premixed swirl flame”, Combustion and Flame, 150 (2007), pp. 2 – 26, for more explanations about the required module. The synchronization module has to be used at both low and high frequency, and so also when using both PIV and PLIF systems. Sesta Lab underlines that both the pressure transducer and the pressure acquisition chain are not object of the supply described in this document.



Pressure signal of the plenum with trigger scheme for the pulsed measurements.



Pressure oscillation compared to a pure sine function; the black curve shows a sine function and the red curve displays the pressure signal of the plenum. The markers ph1–ph8 indicate the assigned phase angles at which measurements were performed. These were ph1 = 0°, ph2 = 50°, ph3 = 105°, ph4 = 150°, ph5 = 195°, ph6 = 230°, ph7 = 270°, and ph8 = 315°.

Figure 2: Synchronization of the lighting/acquisition processes on the oscillation frequency of the pressure inside combustion chamber

Finally, Sesta Lab asks for the supply of 4 pairs of glasses opaque to the 532nm and UV wavelengths and in agreement with the laser sources described in the current document.

In the following all the components that shall be included in the laser systems supplied are summarized. The list is not the list of all the necessary components for the delivery of "turnkey" PIV and PLIF/Rayleigh Thermometry laser systems. The supplier has to submit to Sesta Lab, for each component, the technical specification and all the necessary documents that can prove the agreement with what requested in the present document.

PIV system		
Item	**Plus**	**Qnt**
Laser Nd:Yag (o Nd:YLF) a double cavity, 5mJ/pulse @5kHz, 13mJ/pulse @1kHz	E > 5mJ/pulse @5kHz E >13mJ/pulse @1kHz	1
Time compensator between laser pulse and Q-switch trigger		1
High Speed Camera, CMOS, 1280 x 800 pixel, 5kHz, 12bit, 64Gb, fast Ethernet, with cables and interfaces.	R = 1600 x 1200 pixel (2MP) R > 2048 x 1536 pixel (3MP) > 12bit	2
Objective with focal length included between f = 85mm e f = 105mm, at least F/2.8, manual	Objective F = 200mm, at least F/2.8, F-mount, manual	2
Rail for high speed camera, with manual regulation system of the position.		1

Scheimpflug manual system, compatible with the cameras	Motorized Scheimpflug	2
Green filter 532nm (or 527 nm)+/- 10nm.		2
PIV Calibration kit, 2D e 3D, (plate) 50x50mm2, 5mm pitch, 1.5mm diameter dots.		1
Seeding generator, working inside the range [1 -15]bar, 0.25 kg/s	T = 600°C	1
Seeding TiO_2, [0.5-4] μm		5 kg
Seeding Al_2O_3, [0.5-4] μm		5 kg
PLIF/Rayleigh Thermometry system		
Nd:Yag, 10Hz @532nm, pulse duration not exceeding 10ns. 400mJ/pulse @10Hz	120mJ/pulse @10Hz @355nm (alternative to 400mJ/pulse @10Hz)	1+1
Dye Laser, 20mJ/pulse @10Hz @283.2nm	E > 20mJ/pulse @10Hz @283.2nm F > 10Hz with at least 5mJ/pulse @20Hz @ 283.2nm	
Laser shutter		1
Dye laser pulse monitoring energy system		1

High Speed Camera, CMOS, 1280 x 800 pixel, 30Hz, 12bit, recommended 16Gb, fast Ethernet, complete of cables and interfaces.	R = 1600 x 1200 pixel (2MP) R > 2048 x 1536 pixel (3MP) > 12bit	2
UV objective with focal length included between f = 85mm e f = 105mm, at least F/2.8, UV transparent from at least 200nm.	UV objective with focal length f = 200mm, at least F/2.8, UV transparent from at least 200nm	2
Signal intensifier in the range [200 – 750] nm, min exposition 10 ns, compatible with the supplied high speed cameras.		2
UV filter 320nm +/- 20nm, with max performances on the OH emission wavelength. Transmission > 70%.		1
Filter 355nm +/- 5nm. Transmission > 80%.		1
266nm UV filter with FWHM +/- 10nm. Transmission > 60%		1
UV dye laser collimator		1
Dye kit for dye laser		1+1 recharge

	System for laser light shaping in a structured sheet	1
Parts in common for PIV and PLIF/Rayleigh Thermometry systems and software.		
Rail, holder, lenses with low UV absorbance, (from 200nm), lenses/telescopic objectives for the laser sheet shaping, laser tubes for beams delivery to the Test Section, UV mirrors, beam splitter (optional) for both PIV and PLIF measurements		2
UV transparent "beam combiner"		1
	Mechanical supports (structures) for the delivery of the laser beams to the Test Section.	-
Laser dampers for the lasers source in use.		2°
PC dual processors, core not less than 12, keyboard, mouse, DVD reader, hard disk of 4 TB, schermo da 24", OS Windows.		2°

GPU package (hardware e software) for performance increasing for PIV images post-processing		1
Control, acquisition and post-processing commercial software (the supplier must be the owner of the official supplier); formats: BMP, JPG, TIF, Tecplot, DAT, TXT, PS, AVI. The software shall operate calibration processes, distorsion reduction actions, masking, image post-processing, both for PIV and PLIF/Rayleigh Thermometry measurements.		2°
Software module for PIV		1*
Software module for PIV 3D		1*
Software module for PLIF		1*
Software module for the correction and calibration of the laser beams.		1*
Life time updates for the required software + software update with new releases for the next 5 years.		1
PLIF/PIV synchronizer, up to 5 kHz		1

PLIF/Rayleigh Thermometry Synchronizer		1°
	Trigger on the combustion pressure harmonic, acquired during the test.	1
Optical table 1500mmx1800mmx200mm (with dumpers)		1
Opaque glasses to 532nm (527nm) and to UV		4

*= if not already included by default in the supply.

°= the supplier must justify. Eventually the supply of only one synchronizer is possible, but only after Co.Svi.G. Sesta Lab official approval.

The description reported in the current technical are only explicative and shall not be considered as a summary of the whole supply. Moreover, the supply should include everything, even not clearly described, necessary for the supply of two "turnkey" PIV and PLIF/Rayleigh Thermometry systems, on the basis of the submitted Test Cell sketch, which will host the laser systems.

Sesta Lab requires, before the delivery of the systems, the performance check for each component and the full commissioning of the systems at its workshop/office, attended by Sesta lab technicians. The commissioning will include:

- Inspection of components
- Performance check on each component
- PIV and PLIF/Rayleigh Thermometry setup
- PIV and PLIF/Rayleigh Thermometry test run

- Overall performance check.

Moreover Sesta Lab requires that the supplier will perform the PIV and PLIF/Rayleigh thermometry systems commissioning at Sesta Lab (or in another place of Italy indicated by Sesta Lab). Sesta Lab asks for a training on the system object of the present technical specification. For commissioning activities at Sesta Lab and for training Sesta Lab asks 10 working days to the supplier, including travel expenses, board and lodging. The supplier has to be available for the commissioning test during 2018.

In the case Sesta Lab decides for a commissioning after more than 3 months from the laser systems delivery, Sesta Lab asks the supplier to propose a procedure for the components maintenance, in order to preserve the use, the quality and the guaranty.

Finally, Sesta Lab requires to the supplier to grow up two technicians on PIV and PLIF with courses and/or seminars.

Sesta Lab asks to have direct access to the supplier service in case of maintenance of the laser systems and in case some problems will arise during mounting/alignment/test of the laser systems. Sesta Lab asks the supplier for one or more people which will be the direct contact between Sesta Lab and the supplier for after sale service.

4. Tolerances

The values reported in the present document should be considered subjected to a tolerance of +/- 10% to the nominal value. Components exceeding the tolerance will be rejected by Sesta Lab. Exception made for the following items:

- Lasers sampling frequency: +/- 5%.
- Cameras sampling frequency: +/- 5%.
- PIV cameras memory: +/- 15%.
- PLIF cameras memory: +/- 25% (or the closest value to that described in this technical document and available on the market).

- Laser light attenuaton from the laser source to the Test Rig: as described in the present document.

5. Shipment

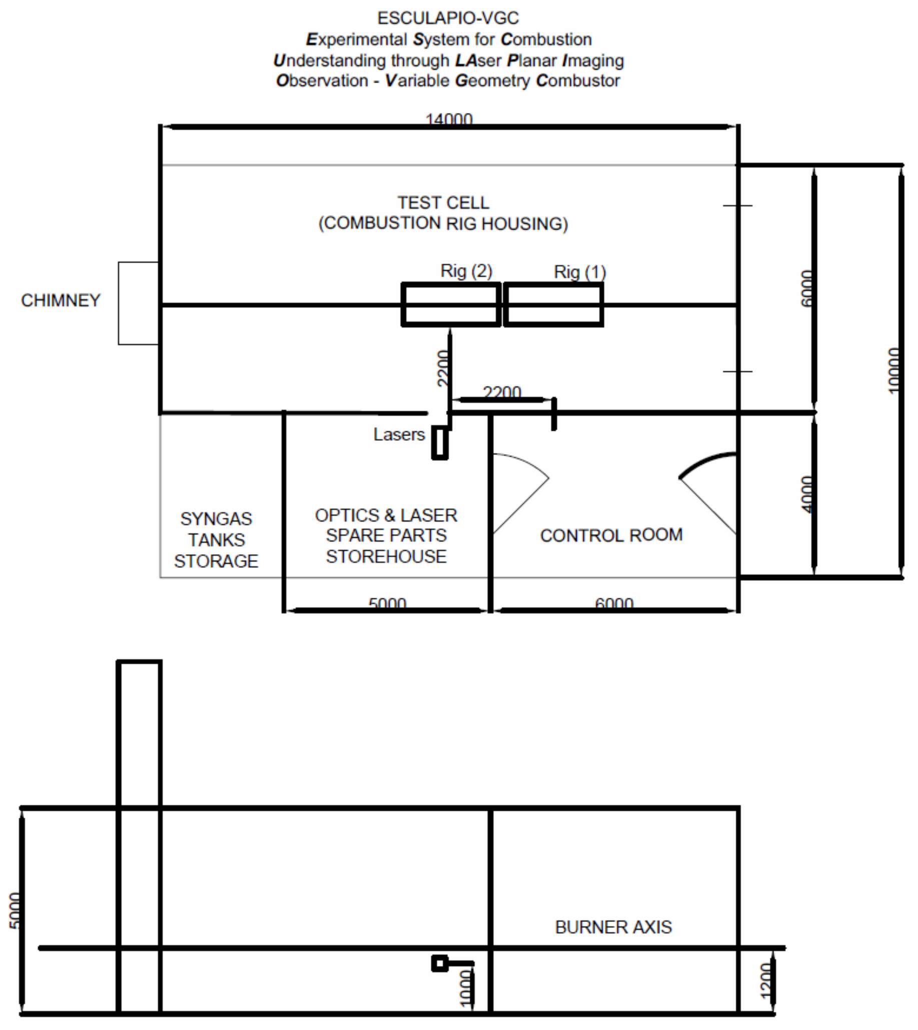
The supply is intended “free port”. So the supply will include the shipment to Sesta Lab and the unload of the shipment in Sesta Lab. The shipment should have a proper packaging. Sesta Lab will communicate to the supplier the place for the delivery, which could be different than Sesta Lab, but in any case in Italy.

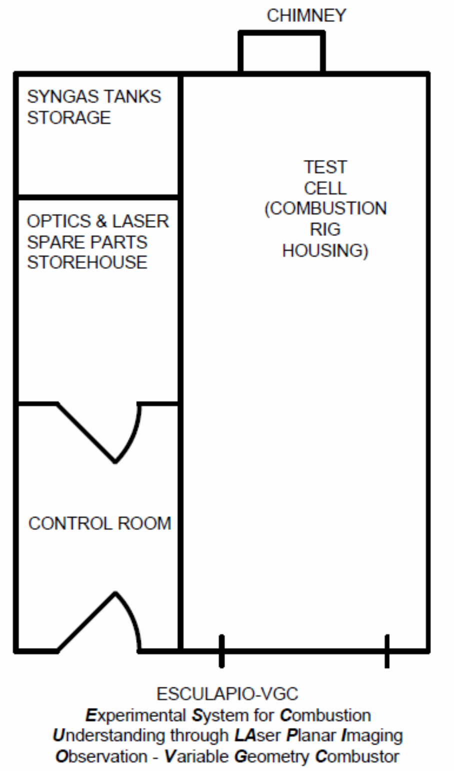
6. Controls

Co.Svi.G Sesta Lab has the possibility to attend to all the checks that the supplier will have to do on the laser systems before the shipment as well as to the commisioning at the supplier office.

7. Guaranty

The supplier will have to substitute or free repair (in all the cases not responsibility of Co.Svi.G. Sestya Lab) all the defected, not compliant or damaged components, during the guaranty period reported in the contract. The whole supply will be guarantyd 24 moths from the delivery date of the laser systems (whole assembly) to Sesta Lab or in another place indicated by Sesta Lab (however, still in Italy).





Sketch of Test Cell 3