IFCPAR/CEFIPRA PROJECT IDENTIFICATION

PROPOSAL N°:
(to be filled byIFCPAR)

AREA: 01

TITLE in English:
(50 char. at most)

Relaxation Schemes for Hyperbolic Conservation Laws in Lagrangian-Eulerian framework

TITLE in French:
(50 char. at most)

Schéma de relaxation pour lois de conservation hyperboliques dans un contexte de type Lagrangien-Eulérien

PRINCIPAL COLLABORATOR (Indian): Name and Affiliation

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SUMMARY (English): 10 lines max. (10 pts font)

The proposed French collaborators have expertise in Lagrangian methods and Discrete Velocity Boltzmann methods while the Indian collaborators have expertise in Eulerian methods for simulating hyperbolic conservation laws numerically. It is proposed to utilize these complimentary expertises in developing new algorithms for hyperbolic conservation laws, starting with Euler equations of gas dynamics. The total convection terms are planned to be split into convective and pressure parts, with Lagrangian schemes to be used for simulating convection while a discrete velocity Boltzmann scheme in the Eulerian framework is planned for the pressure terms based in a novel meshless framework. The above novel method will be tested on various Euler test cases first in 2-D and further work in 3-D and various extensions of the idea will be initiated.

RÉSUMÉ(Français)): 10 lignes max. (10 pts font)

Les collaborateurs français à ce projet sont des spécialistes des méthodes lagrangiennes et des méthodes Boltzmann à vitesses discrètes, tandis que les collaborateurs indiens sont spécialistes des méthodes eulériennes pour la simulation numérique des lois de conservation hyperboliques. Nous proposons d'utiliser ces compétences complémentaires pour développer de nouveaux algorithmes pour les lois de conservation, en commençant par les équations d'Euler de la dynamique des gaz. Nous envisageons de séparer les termes de flux en une partie convective et une partie pression, afin de traiter la convection par méthode lagrangienne, alors qu'une méthode de type Boltzmann à vitesses discrètes sera utilisée pour les termes de pression, dans un cadre eulérien qui utilise un nouvelle approche sans maillage. Cette nouvelle méthode sera testée sur différents cas en 2-D (puis en 3-D), et des extensions variées de cette approche seront envisagées.

PROPOSAL FOR COLLABORATIVE ADVANCED RESEARCH
COVER–SHEET

I   –(To be filled in by the Principal Collaborator who initiates the Proposal)
Dear

As per the IFCPAR/CEFIPRA guidelines, I have incorporated inputs from my side in the proforma and am sending it to you. You may kindly enter the relevant inputs from your side, and return the completed proforma to me along with the certificate from the Head of your institution as given in the Annexure.

<div style="text-align:right">

Signature
Name
(Principal Collaborator from
India/France)*
</div>

Forwarded to:
(Principal Collaborator from
 India/France) *
Strike out whichever is not applicable

_____

II   –(To be filled in by the Second Principal Collaborator from the other country)

Dear

I have completed the proposal in all respects and am returning it to you for further necessary action. I have enclosed the certificate from the head of my institution in the format given by IFCPAR.

<div style="text-align:right">

Signature
Name
</div>

* Strike out whichever is not applicable   (Principal Collaborator from
                                                              India/France)*

Returned to the
Principal Collaborator
who initiates the proposal

_____

III   –(To be filled in by the Principal Collaborator who initiates the Proposal)
To
The Director
IFCPAR
New Delhi
Sir,

     Enclosed please find twelve copies of the Proposal for Advanced Collaborative Research being submitted jointly by me and_____(name)_____ of _____(institution)_____for your consideration. I also enclose the certificates from the heads of the respective institutions in the format given by you. In the event of our proposal being accepted, we agree to abide by the terms and conditions to be stipulated by you.

<div style="text-align:right">

Signature
Name
</div>

* Strike out whichever is not applicable   (Principal Collaborator from
                                                              India/France)*

To: The Director,
Indo–French Centre for the Promotion of Advanced Research
5B, Ground floor, India Habitat Centre
Lodhi Road, New Delhi–110 003 INDIA

Part I : PROJECT DESCRIPTION and other Related Information

The detailed description, both in English and French, of the project should be organised within the six (items 110 to 160) following items with an overall length not exceeding 5000 words *(boxes will expand with increasing text length)*

110. Objectives of the project :

The genesis of the numerical simulation of Hyperbolic Conservation Laws is in the mid 1940s. Roughly speaking, it coincides with the appearance of "computers" in the U.S. during World War II at Los Alamos National Laboratory. At this time the first numerical method was, in modern appellation, of a Lagrangian type : the mesh moving with the fluid velocity encompasses compression/expansion as the fluid does. Since the 50s a tremendous number of numerical methods have been mathematically studied, especially Eulerian ones : the mesh being fixed sees fluxes travelling across cell edges. Parallel to these two types of frameworks the imagination of the new born world of Scientific Computation gave birth to: meshless methods for which particles carry all the necessary information, Kinetic or Boltzmann schemes based on Kinetic Theory of Gases and the closely related idea of relaxation methods for which the numerical scheme does not try to approach the solution *per se* but rather relaxes towards it instead, etc..

No approach is superior to any other for all situations; for instance, Lagrangian schemes exactly resolve any contact discontinuity contrarily to Eulerian ones, Eulerian schemes are well analysed and robust contrarily to Lagrangian ones, meshless or grid-free algorithms require much less effort for grid generation in contrast to fixed mesh methods, Kinetic Schemes and Relaxation Schemes, based on efficient linear models, are simpler than the traditional Eulerian algorithms like Riemann Solvers, etc.. Therefore, research to improve each of them is still an ongoing work as well as research to marry them.

In this project, we would like to follow the quest in extruding the best of each of these concepts within the same numerical method. We will focus on Euler equations in 2D (further in 3D) to begin with, keeping in mind that any development should not be specific to Euler equations only and should be applicable to other hyperbolic conservation laws like the Shallow Water equations, equations of magneto-hydrodynamics. The Euler equations, which are non-linear conservative hyperbolic PDEs, are analytically well known and therefore form a good academic starting point for our investigations.

We intend to

i) Analyse which part of the PDE could be better solved by Lagrangian, Grid-Free, Eulerian machinery, relaxation or kinetic schemes;

ii) Explore different already known schemes from each world to point out the most efficient ones, eventually study the opportunity to go beyond such existing methods;

iii) Study the amalgamation of these different methods together with all the mathematical theory and analysis one needs to testify the *a priori* good/bad behaviour to expect;

iv) Write a simulation code in 2D to numerically test the obtained method on the "zoology" of known test cases (from simple Sod problem to Rayleigh-Taylor instability, from stationary contact discontinuity to astrophysical type of explosion in multi-species domain);

v) Improve, ameliorate and understand the limiting behaviour of the numerical method;

vi) Conclude on the opportunity to write a 3D code, eventually start a toy 3D code for a numerical proof of feasibility.

120. State of the art (with relevant references from major journals) :

Lagrangian Framework

The birth of numerical methods for solving physical problem is related to the development of computers in the 40s, themselves intimately related to calculations carried out for the development of nuclear bomb during World War II. Von Neumann in [VR] opened this world of scientific computation with a Lagrangian numerical method and soon after Richtmyer [Richt67] wrote his well-known book on difference methods where many basic concepts were introduced to the community. Lagrangian methods, for which the mesh moves with the fluid velocity, have been widely used, especially for applications where the characteristic mesh size decreases (or increases) tremendously during the simulation time (astrophysics, nuclear simulation, laser/plasma interactions...). Von Neumann staggered grid method is one the oldest but still in used Lagrangian numerical method (in its modern and improved form see the recent work by Loubère et al. in [BBCLS06]).

From this seminal paper of von Neumann, many numerical Lagrangian schemes have been developed; cell-centered type, Godunov type, Particle-In-Cell type, 2D/3D, Cartesian, axi-symmetry, etc. Even well recognized for its ability to exactly catch and preserve contact discontinuity, Lagrangian methods usually suffer from their lack of robustness when the mesh/solution becomes highly distorted. One solution developed in the 90s (see [Ben92] and Benson's bibliography) is the so-called Arbitrary-Lagrangian-Eulerian (ALE) framework for which Lagrangian time steps are followed by a rezoning/smoothing step (geometrical improvement of the mesh) and a remap (projection from the Lagrangian mesh onto the rezoned one, see specifically the recent work by Loubère et al. in [LS5]). By doing so the natural diffusion implied by the remap phase coupled with the good geometrical quality of the mesh due to the rezoning/smoothing phase makes the ALE method more robust. However the burden of carrying a mesh and smoothing it from time to time leads to difficulties to handle complex situations and/or mesh. One other solution is to "free" the Lagrangian numerical scheme from the notion of mesh; a type of Grid-Free, or Free-Lagrange, or Particle methods (Smoothed Particle Hydrodynamics). None of the pre-cited methods are absolutely superior to the others. However the good realizations of the mixing of frameworks as in the ALE concept lead to general improvement of the approximation so that this ALE concept is now widely used in real simulation codes (ALE INC(ubator) in nuclear world at Los Alamos National Laboratory U.S.A, astrophysics, CHIC code in laser-plasma interaction field at University of Bordeaux, France as instance).

Eulerian framework

Contrary to the Lagrangian methods, the Eulerian algorithms use a steady mesh which does not move with the fluid. This avoids the use of complicated remeshing and remaping procedures of the Lagrangian approach. The Eulerian algorithms for solving nonlinear hyperbolic conservation conservation laws like Euler equations of gas dynamics have reached a mature phase of development and now are considered industry-standard for applications. They can be broadly classified into *central discretization algorithms* and *upwind or upwind-biased schemes*.

The central discretization methods were the first successful hyperbolic equation solvers and were developed in 1960s to 1980s. The popular ones belonging to this category are due to Lax & Friedrichs, Lax & Wendroff, MacCormack and Jameson, Schmidt & Turkel. These schemes form stable

algorithms for simulating hyperbolic equations essentially by the addition of artificial viscosity or numerical dissipation to the central discretizations. To control the right amount of artificial viscosity to get oscillation-free solutions, it became necessary to introduce control parameters, which became problem-dependent, and this was a major criticism against these methods.

In contrast, upwind methods have an inherent artificial viscosity and became popular from the 1970s. Majority of the upwind schemes can be categorized into four major groups : *Riemann Solvers (exact or approximate), Flux Splitting Methods, Kinetic (or Boltzmann) Schemes and Relaxation Schemes*. The approximate Riemann solvers, like the scheme of Roe, are very accurate in resolving steady discontinuities, but are known to lose robustness in some cases, leading to unphysical solutions like carbuncle shocks, kinked Mach stems and odd-even decoupling. Another disadvantage associated with the popular Roe scheme is the violation of entropy condition which makes the addition of parameter-dependent artificial viscosity necessary, leading to an *entropy fix*. These problems led the researchers to search for Riemann-solver-free algorithms in the recent years. Flux Vector Splitting methods like those of Steger & Warming and van Leer are robust but are less accurate than the approximate Riemann solvers in resolving discontinuities.

Kinetic and relaxation schemes that are based on the interpretation of fluid mechanics by the kinetic theory of gases are also Riemann-solver-free algorithms. Since these schemes are of particular interest in our project, we briefly comment on their main properties. As instance, in the Euler system of fluid mechanis, the state of the gas is described at every time and position by the conservative variables (mass density, momentum, energy) and their corresponding evolution equations that form a non linear hyperbolic system. In the kinetic theory, the gas is described at the particle scale by a scalar velocity distribution function that depends on an additional variable: the particle velocity. The moments of this function in the velocity space are the usual conervative variables used in fluid mechanics. The evolution of this function is governed by a kinetic equation: this is a semi-linear hyperbolic equation that contains a linear convection operator, which represents the transport of particles along straight lines, and a non-linear local operator that models collisions between particles. The link between these two descriptions is that when the microscopic scale (for instance the mean free path of the particles) is small as compared to the macroscopic scale (the lenght of the domain), the distribution function converges to an equilibrium function of which the moments are exactly the solution of the Euler equation (see details in [Ce])

Note that the detailed structure of the collisions is not needed in this derivation: it is only needed that the collision operator admits equilibrium states that correspond to the variables of the Euler equations. Generally, the collision operator can be simply taken as a relaxation operator towards this equilibrium (this is now called a BGK model of the collisions). In fact, many conservation laws can be formulated as limit models of kinetic equations, even when the kinetic interpretation has no clear physical meaning (see for instance the pionner work of Brennier [Br] and many examples and references in [Pe1]). This interpretation is the basis of two classes of numerical schemes for conservation laws: kinetic and relaxation schemes.

The idea of kinetic schemes goes back the work of Sanders and Prendergast [SP], then Pullin [Pu] and Deshpande [MD]. The kinetic formulation of the conservation law is combined with a simple time splitting scheme between the convection and the collision phenomena: first the macroscopic variables are used to define the corresponding kinetic equilibrium function. Then, this equilibrium is convected according to the convection part of the kinetic equation by using a standard finite volume scheme. According to the collision part, this new distribution is projected to its corresponding equilibrium state, which gives updated macroscopic variables. This procedure finally gives a numerical scheme for the Euler equations in which the kinetic interpretation is removed. Its advantage is that there is no

need to use Rieman solvers or complicated flux splitting, and these schemes can be proved to be very robust (stability, positivity, conservation).

More recently, the relaxation schemes proposed by Xin and Jin [JX] have lead to an additional simplification of kinetic schemes. It has been found that in the kinetic interpretation, using a continuous velocity variable, that is to say infinitely many particle velocities, is not necessary. Instead, a very small number of discrete velocities is sufficient, provided that these velocities satisfy some constraints needed for the stability of the kinetic approximation. This kinetic interpretation of the work of [JX] has been proposed by Aregba-Driollet and Natalini [AN]: it is called a discrete kinetic approximation of conservation laws. By using the same discretization procedure as for kinetic schemes, this approach also yields to very simple and robust schemes. These schemes are simpler than the Kinetic Schemes and can be thought of as the simplest of all the upwind methods. However, they are quite dissipative. Recently, some efforts are made to make these schemes more accurate in resolving the discontinuities by [AN] and Raghurama Rao & Balakrishna in [RB]. The common main advantage of these approaches is that the nonlinear fluxes of the conservation laws are replaced by a linear convection term. This allows to construct numerical schemes by choosing within the large variety of existing numerical methods for linear convection.

There are also other interesting algorithms which fit in more than one of the above categories, like the scheme of Coquel & Meng-Sing Liou and Steffen & Meng-Sing Liou. The scheme of Steffen and Meng-Sing Liou, as well as another algorithm of Jameson, is based on splitting the total convection terms into convective and pressure parts, utilizing the properties of each of them separately. This separation of two distinct physical processes embedded in the convection is a potentially rich idea which is not fully exploited yet. In our proposal, we intend to utilize this separation to our advantage by using complimentary approaches. *In conclusion, one can say that an ideal scheme, which is robust, accurate, satisfies entropy conditions and mimics the physics of the flows or the physical solutions of the hyperbolic equations closely are still elusive and the search for an ideal scheme still continues.* It is with this back-ground that our proposal to combine the Lagrangian and Euler approaches with complimentary advantages becomes an interesting alternative.

Grid-free or Meshless methods

Grid generation for complex practical applications is a tedious task to which lot of man-hours and coding effort goes on in the industry and is still riddled with problems. In this context, researchers started looking at algorithms which operate without any traditional grid topologies, essentially working on arbitrary clouds of points. Starting from the early works on Smooth Particle Hydrodynamics by Lucy [Lc] and Gingold & Monaghan [GM], several interesting approaches were introduced to develop meshless methods. For a comprehensive summary of these methods, we refer to Duarte [D] and Belytschko, Krongauz, Organ, Fleming & Krysl [BKOFK] and Liu [L]. It is a part of our proposal to combine the different frameworks of Lagrangian and Eulerian algorithms, Relaxation Schemes and grid-free approaches to develop an efficient algorithm to simulate nonlinear hyperbolic conservation laws digitally. We propose to introduce a new concept of meshless method by using the idea of relaxation system together with the concept of solving it by appropriate interpolations on relevant stencils, utilizing this strategy for the pressure terms in the convective-pressure splitting strategy.

Related works

Finally, we mention related problems that we intent to study. We believe that the results obtained by the participants to this proposal in complementary fields could be fruitfull for the numerical approximation of fully kinetic problems. Indeed, any accurate methods developed for linear

convection (in particular the meshless method of Rao and coworker [BR]) could be used to approximate the transport part of kinetic equations themselves. This has been used by Sonnendrücker et al. [So] for the Vlasov equation by using a semi-lagrangian approach. Up to our knowledge, applying (deterministic) grid free methods to kinetic problems has never been investigated. Since Mieussens has written a code to solve the Boltzmann equation of rarefied gas dynamics [Mi1,Mi2] that uses the finite volume approach, our project is aimed to modify it by a grid free method.

Another closely related problem for which we want to combine our different works is: how to improve the numerical coupling between fluid and kinetic descriptions? Indeed, in this very important field, the computational cost of a gas flow simulation at the kinetic level is reduced by using both fluid or kinetic descriptions wherever it is necessary. Two recent methods have been proposed by Mieussens an coworkers in [DJM] and [DLM] in which coupled fluid/kinetic models have been presented. There is no doubt that possibly innovating numerical techniques for kinetic and/or fluid problems would be fruitfully applied to such models.

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130. Novelty of the project :

This project aims to bring together research workers who are focused on various aspects of numerical methods for hyperbolic conservation laws in both India and France, so that consolidated effort goes into tackling interesting problems in this area. The gathering of experts of different numerical methods will necessarily incubate promising ideas and different angles to tackle open problems. As instance we expect the amalgamation of methods used at their best to produce interesting behaviours especially in the following domain/fields/applications:

1) Simulation of hyperbolic conservation laws with various source terms;

2) Obtaining of genuinely grid-free methods with the robustness of Eulerian approach and the accuracy of Lagrangian ones on contacts;

3) An analytical way of naturally and dynamically adapting the number of generators/grid-points to the solution;

4) A systematic approach to detect which part of a PDE is to be solved by the most appropriate methods.

140. Work plan and methods :

The French team has been working on some of the problems mentioned. L. Mieussens has studied new methods to couple fluid and kinetic models, like Euler and Boltzmann equations, as well as some specific numerical methods (finite volume, discrete-velocity methods). R. Loubère has studied the mathematical properties of staggered Lagrangian schemes for compressible hydrodynamics and the so called "Free-Lagrange" (a type of Grid Free method).

At the Indian side, S.V. Raghurama Rao and S.M. Deshpande developed a Kinetic Scheme based on convection-pressure splitting earlier [RD]. This work was carried further in the work of S. Jaisankar and S.V. Raghurama Rao [JR] in which the Kinetic Scheme based on convection-pressure splitting was made less diffusive by using a diffusion regulation mechanism based on jump in the Mach number at a cell interface in a finite volume method. The convection-pressure splitting introduced in [RD] has a lot of potential for further research as it represents a *unidirectional-multi-directional splitting*, and the proposed research plan carries this work further by exploiting this physical feature.

Futhermore, the partner groups in Toulouse and Bangalore will also interact for FICUS Programme designing and carrying out Cyber courses, starting from January 2008 for the next two years. The two groups have already been working together for the Cyber-University courses (FICUS) for the past two years and several visits of scientists from and to both the places have already taken place under this programme.

Our plan is to initiate joint collaborations and make progress first in the directions mentioned above in the objective of the project. For this, two visits of the Indian side are already planned for the end of year 2007. During these visits, main ideas for tackling the problem will be arrived at. These will be followed up by the visits from the French side which is well trained in the numerical methods for the fluid and kinetic equations. Hence a fruitful exchange of ideas is expected and a smooth progress is envisaged.

The beginnig of the project will be devoted to the development of a new kind of discretization of the Euler equations by splitting the fluxes into a convective part (to be treated by Lagrangian methods) and a pressure part (to be treated by Eulerian methods). The mathematical properties of this method will be studied (stability, positivity, conservation, entropy). The implementation of the inspired numerical schemes in a 2D compressible simulation code will be initiated. The expertise we already have makes this first step attainable.

At the same time, we would like to progress in studying the efficiency of such a splitting for other systems of equations: Magneto-Hydro-Dynamics, Astrophysical flows, Bi-temperature/Bi-fluid models. Moreover, we would like to investigate the opportunity of using these novels ideas to extend the approach towards a genuinely Grid-Free type of method.

150. Part of the project work, which will be conducted in each country, clearly bringing out the added value due to collaboration and the infrastructure facilities related to the project activity available in the institutions where the project work will be carried out :

It is not easy to define precisely which part of the work will be done in which country. Both numerical and theoretical issues need to be discussed jointly during the visits. Once main ideas are obtained, these can be further developed in respective places, maintaining discussions through email, fax and phone. However most of the implementation of the numerical methods will be carried out by the Indian team (more specifically by the hired PhD student) although the good infrastructures both in France and India permit to share the burden.

We expect to give momentum to the project during the respective visits of the collaborators abroad. Indeed, the duration of any stay (roughly one month) will be devoted full time to the progress of the project and will drag the locals to unbind their schedule.

Any theoretical part of the project can be carried out by one of the team but is foreseen to be a joined task that could be enriched after the initial discussion. Both teams are experts in specific numerical methods that are expected to be complimentary within this project; Lagrangian, moving mesh methods and kinetic schemes in Toulouse, and, Eulerian, Grid-Free and relaxation methods in Bangalore. Moreover both teams will obviously benefit from their local environment and expert colleagues in related fields who are not directly related to the project, as instance: N.Ben Abdallah, M.Masmoudi in Toulouse and A.S. Vasudeva Murthy in Bangalore.

Open-minded discussions, comparisons of ideas/results from both sides will clearly be a good stimulation for the emergence of new concepts.

160. Potential applications (if any) :

Hyperbolic equations are very important for a tremendous number of physics related applications. The development of improved numerical methods obviously would positively impact all these fields. As instance we could mention (but it is impossible to give an exhaustive list):
* Astrophysics (explosion of super novae);
* Laser/plasma oriented problems (ITER);
* Initial Confinement Fusion: LMJ (Laser-Mega-Joule), NIF (National Ignition Facility);
* Nuclear safety;
* Aerodynamics (CFD)
* Civil Engineering (Shallow Water Flows)

170. Suggested referees for evaluation of the project (please suggest not more than five Indian and five French referees with their addresses <u>including e-mails</u>. *You*

may also indicate name(s) of scientists to whom the proposal should not be sent, in your opinion, for reasons of conflict of interest.

Proposed French referees
1 – R. Abgrall, Institut de Mathématiques de Bordeaux, Université Bordeaux 1, 351 cours de la Libération 33405 Talence cedex, *abgrall@math.u-bordeaux1.fr*

2 – B. Després, Laboratoire Jacques-Louis Lions, Université Paris VI, Université Paris 6, 175 rue du chevaleret, Paris XIII, 75013, Paris, *despres@ann.jussieu.fr*

3 – F. Filbet, Institut Camille Jordan, Université Claude Bernard Lyon, 43 Bd du 11 Novembre 1918, 69622 Villeurbanne cedex, *filbet@math.univ-lyon1.fr*

4 – M. Lemou, Université de Rennes 1, Campus de Beaulieu, 35042 Renne cedex, *mohammed.lemou@univ-rennes1.fr*

Proposed Indian referees
1- Prof. M.Vanninathan, TIFR Centre, P.O.Box.1234, IISc Campus, Bangalore-560 012, India, Tel. : 91-80-2360 0062,2360 0138,2360 0816, Fax: 91-80-2360 0851, vanni@math.tifrbng.res.in

2- Prof. A.S. Vasudeva Murthy, TIFR Center, Indian Institute of Science, Banglore, Karnataka, India, Tel. : (O) 91- 80 -23600062, (R) 91 - 80 – 23371570, ma28@vsnl.net

3- Prof. Amiya Kumar Pani, Industrial Mathematics Group, IIT Bombay, Powai, Mumbai – 400076, Maharashtra, India, Tel. : (O) 91-22 – 25768481, (R) 91-22 – 25767481, (FAX) 022 – 25723480, akp@math.iitb.ac.in

4- Prof. Mohan K. Kadalbajoo, Department of Mathematics, Indian Institute of Technology, Kanpur, Kanpur – 208 016, India, Tel. : (O) 91-512-2597732, (R) 91-512-2598285, Fax : 91-512-2597500, kadal@iitk.ac.in

5- Prof. Pravir Dutt, Department of Mathematics, Indian Institute of Technology, Kanpur, Kanpur – 208 016, India, Tel. : (O) 91-512-2597074, (R) 91-512-2598594, Fax : 91-512-2597500, pravir@iitk.ac.in

---

180. Currently running projects (titles, funding agencies, budgets, starting date, duration) :

R. Loubère: Funding Agency EGIDE Barrande Franco-Czech project "*Dev. Of numerical methods of Lagrangian and ALE types for laser-plasma applications*"
R. Loubère: contract with CEA (French Atomic Energy Commission) to be validated by institutions – 8000 euros for 1 year, expected starting date Sept.07 – Title: "*Study of multimaterial ALE method*"

L. Mieussens, project "Kinetic and hydrodynamic models for the dynamics of micro and nano fluids", funded by CNRS (National Center of Scientific Research) with PICS (Project of Scientifc Cooperation, International Program) grant N°3195, budget 28000 euros, started in 2005, for 3 years.

S.V. Raghurama Rao, Development of Base-line CFD Codes for the Shape Optimzation of Submeged Intakes, Aeronautical Development Establishment, Rs. 9,75,000, started in 2006, to be completed in 2007.

PART II– TIME SCHEDULE

210. A   Duration of the project :

Three years

210. B   Please indicate the approximate number of man–months in a year to be devoted to this project by each of the Principal and Joint Collaborators :

	Man–months		
	I yr	II yr	III yr
Indian Principal Collaborator	8	9	9
French Principal Collaborator	8	8	8
Indian Joint Collaborator(s)	8	8	8
French Joint Collaborator(s)	8	8	8

220.   Details of phases in which the project will be carried out, with duration of each phase. (Please enclose a Bar Chart)

Phase 1	Initial exchange of ideas Setting up the models and assoc. numerical schemes Mathematical and numerical study of algorithms	First year
Phase 2	Implementation of the numerical methods, tests and validation of the simulation code, comparison with existing results (from literature)	Second year
Phase 3	Progress and improvement of the simulation code in view of the preliminary results of phase 2, Communication	Third year

230. Identifiable outputs at the end of each phase

After Phase 1:
1. Lecture notes of the investigators familiarizing the other side with the problems and their expertise to solve them;
2. Preliminary report on the mathematical theory and numerical analysis of retained methods.

After Phase 2:
1. Seminars by visiting scientists;
2. Preprints on some on-going work;
3. Possible article(s) on first mathematical analysis results to be submitted to international mathematical journals and to conferences.

After Phase 3:
1. More preprints on ideas which have necessarily evolved and/or matured since the first phase is complete;
2. Probable articles on numerical results to be submitted to physics-math oriented journals and to associated conferences;
3. Simulation code almost complete and working.

PART III – BUDGET ESTIMATE*

Manpower to be hired by the Indian Principal Collaborator for the project

JRFs, SRFs, RAs TO BE HIRED BY THE INDIAN COLLABORATOR SPECIFICALLY FOR THE PROJECT

Designation	Number	1st Year (Rs.)	2nd Year (Rs.)	3rd Year (Rs.)

			9,500 per month	10,000 per month	10,000 per month
Research Student (PhD)	**1** (3 years)				
Year-wise total			1,14,000	1,20,000	1,20,000
310. TOTAL MANPOWER BUDGET		Rs.	**3,54,000**		

* Kindly indicate the requirements of the Principal collaborator and Joint collaborator separately when they are not from the same institution.

Other Recurring Expenses of the Indian Collaborator

	Details	1st Year (Rs .)	2nd Year (Rs .)	3rd Year (Rs .)
321.	Cost of consumable Materials (station. storage media, printer cartridges)	50,000	50,000	50,000
322.	Cost of project related local travel *within India*	1,10,000	1,10,000	1,10,000
323.	Any other miscellaneous Typing, system administrator support	20,000	20,000	20,000
324.	Year-wise total	1,80,000	1,80,000	1,80,000

320. Total budget on recurring expenses for the project duration

Rs. 5,40,000

Purchase of Equipment by the Indian Collaborator

	Details	1st Year (Rs.)	2nd Year (Rs.)
331.	Cost of equipment to be purchased in India 1 laptop	1,50,000	
332.	Cost of imported equipment, including customs duty		
333.	Year-wise total		

330. Total budget on purchase of equipment by the Indian Collaborator

Rs. 1,50,000

Details of equipment proposed to be purchased :

S.No.	Item	Estimated cost			Detailed Justification
		In foreign* Currency	Exchange* Rate	Cost in Rs.	

* To be given only for imported equipment

NOTE : EQUIPMENT APPROVED UNDER THE PROJECT SHOULD BE PURCHASED EARLY AFTER THE START OF THE PROJECT. IN NO CASE EQUIPMENT PURCHASE WILL BE ALLOWED AFTER THE MIDDLE OF THE PROJECT.

Manpower to be hired by the French Principal Collaborator for the project

POST DOCS/DOCTORAL STUDENTS TO BE HIRED BY THE FRENCH COLLABORATOR SPECIFICALLY FOR THE PROJECT				
Designation	**Number**	1st Year (Euros)	2nd Year (Euros)	3rd Year (Euros)
Postdoc position	**2**		**2735** euros brut / month (with patronal charges and **2027** euros without patronal charges) With A.P.E (10% of 2027) **2938** euros With overhead of the University **3144** euros/month	**38622**
Year–wise total			**37728 euros**	**37728 euros**
340. **TOTAL MANPOWER BUDGET**	**Euros**	**75456 euros**		

Other Recurring Expenses of the French Collaborator

	Details	1st Year (Euros)	2nd Year (Euros)	3rd Year (Euros)
351.	Cost of consumable Materials, printer cartridges	**1000** euros With taxes: **1200** euros	**1000** euros With taxes: **1200** euros	**1000** euros With taxes: **1200** euros
352.	Cost of project related local travel *within France*	None	None	None
353.	Any other miscellaneous 2 Tecplot licences	**1800** euros With taxes: **2000** euros	None	None
354.	Year–wise total	**3200 euros**	**1200 euros**	**1200 euros**

350. Total budget on recurring expenses for the project duration

5600 Euros

Purchase of Equipment by the French Collaborator

Description	1st Year (Euros)	2nd Year (Euros)
. 1 laptop PC Pentium 3.40 Ghz, 2x2Mo cache, Windows XP Pro, 2x1024 Mo RAM, 500 Go HD + accessories 2 Tecplot Licences .	~**3000** euros ~**2000** euros	
Year-wise total	~**5000** euros	

360. Total budget on purchase of equipment by the French Collaborator

5000 Euros

Details of equipment proposed to be purchased

S.No.	Item	Estimated cost (Euros)	Detailed Justification

370. **International Travel**

India to France

	1st Year	2nd Year	3rd Year
371. Proposed number of visits of Indian Scientists to France	2	3	3
372. Duration of stay during each visit of Indian Scientists to France	30 days each	30 days each	30d each

373. Activities proposed to be performed during each visit

1st Year :

Giving lectures on the basic mathematical and engineering fundamentals of the problem, problem formulation with state of the art numerical methods

2nd Year

The first implementation of the numerical methods formulated, testing on bench-mark problems and preparation of preprints of the research work done

3rd Year

Continuation of the testing and application of the numerical methods developed, sending the manuscripts to international journals in mathematics and engineering disciplines, preparation of the final project report

France to India

		1st Year	2nd Year	3rd Year
374.	Proposed number of visits of French Scientists to India	2	2	2
375.	Duration of stay during each visit of French Scientists to India	30 d/each	30 d/each	30 /each
376.	Activities proposed to be performed during each visit			

1st Year
Give lecture on common problems (mathematical theory and numerical methods),
State of art for numerical algorithms for solving the corresponding problems,

2nd Year
The main objectives of these visits is to make possible the emergence of new ideas to design innovative numerical methods,
Write preprints on some on-going works,
First implementation of the methods,

3rd Year
Continuation of the numerical investigations with the simulation code,
Write article(s) on first results to be submitted to international physics-math oriented journals

ANNEXURE A: COLLABORATORS

400. Principal Collaborator from India (Please attach biodata and list of not more than *10 MOST* relevant publications in the last five years)

401. Name and Designation

Dr. S. V. Raghurama Rao

402. Sex   Male $\boxed{X}$ Female $\boxed{}$

403. Date of Birth $\boxed{2 \mid 0}$ $\boxed{0 \mid 8}$ $\boxed{1 \mid 9 \mid 6 \mid 3}$
                              (Date)   (Month)   (Year)

404. Name of the Institution
Centre of Excellence for Aerospace CFD
Department of Aerospace Engineering
Indian Institute of Science

405. Name and Designation of the
Head of the Institution

Prof. P. Balaram
Director
Indian Institute of Science
Bangalore – 560012, India

406. Address :– Institution
Centre of Excellence for Aerospace CFD
Department of Aerospace Engineering
Indian Institute of Science
Bangalore, 560 012 INDIA

Telephone No. : (91-80) 22933031

Fax No.   : (91-80) 23600134

e-mail : raghu@aero.iisc.ernet.in

407. Address :– Residential

Dr. S.V. Raghurama Rao
No. 4, Krishnaraja Apartments
Indian Institute of Science
Bangalore- 560012, India

Telephone No. : (91-80) 23340144

Fax No.   : None

e-mails   : (1) raghu@aero.iisc.ernet.in   (2) svraghuramarao@yahoo.com

Selected publications:

[1] A. Jaisankar and S.V. Raghurama Rao, Diffusion Regulation for Euler Solvers, Journal of Computational Physics, vol. 221, pp. 577-599, 2007.

[2] G.N. Sashi Kumar, A.K. Mahendra and S.V. Raghurama Rao, Shape Optimization using Hybrid GA_ACO Method and Grid-Free CFD Solver, AIAA Paper No.: AIAA-2007-3830, 2007.

[3] S. Jaisankar, K. Shivashankar and S.V. Raghurama Rao, A Grid-Free Central Scheme for Inviscid Compressible Flows, AIAA Paper No. : AIAA-2007-3946, 2007.

[4] K. Arun, S.V. Raghurama Rao, M. Lukacova-Medvidova and P. Prasad, A Genuinely Multi-dimensional Relaxation Scheme for Hyperbolic Conservation Laws, submitted, 2007.

[5] S. Jaisankar and S.V. Raghurama Rao, A Discrete Rankine-Hugoniot Solver for Hyperbolic Conservation Laws, submitted, 2007.

{6] S. Balasubramanyam and S.V. Raghurama Rao, A Grid-free Upwind Relaxation Scheme for Inviscid Compressible Flows, International Journal for Numerical Methods in Fluid Dynamics, vol. 51, pp. 159-196, 2006.

[7] Dominic S. Chander, S.V. Raghurama Rao and S.M. Deshpande, A One Point Shock Capturing Kinetic Scheme for Hyperbolic Conservation Laws, book chapter, Computational Fluid Dynamics 2004, (eds.) C. Growth and D.W. Zingg, Springer-Verlag, 2006.

[8] G.N. Sashi Kumar, A.K. Mahendra and S.V. Raghurama Rao, Aerodynamic Shape Optimization Using Ant Colony Optimization Coupled With Computational Fluid Dynamics Solver, book chapter, Computational Fluid Dynamics 2006, to be published by Springer-Verlag.

[9] S.V. Raghurama Rao and K. Balakrishna, An Accurate Shock Capturing Relaxation Scheme for Hyperbolic Conservation Laws, AIAA Paper, no. AIAA-2003-4115, 2003.

[10] S.V. Raghurama Rao and M.V. Subba Rao, A Simple Multi-dimensional Relaxation Scheme based on Characteristics and Interpolation, AIAA Paper no. AIAA-2003-3535, 2003.

450. Principal Collaborator from France (Please attach biodata and list of not more than **10** *MOST* relevant publications in the last five years)

451.   Name and Designation

Dr. Luc Mieussens

452.   Sex   Male X   Female

453.   Date of Birth   3   0   0   6   1   9   7   2
                          (Date)   (Month)   (Year)

454.   Name of the Institution
Université Paul Sabatier Toulouse 3

455.   Name and Designation of the
Head of the Institution
Prof. J.-F. Sautereau

456.   Address :– Institution
        Institut de Mathématiques de Toulouse,
        (équipe Mathématiques pour l'Industrie et la Physique)
        Université Paul Sabatier Toulouse 3,
        31062 TOULOUSE cedex 9, France

        Telephone No. : (33) 5 61 55 76 43

        Fax No.   : (33) 5 61 55 83 85

        e-mail : mieussens@mip.ups-tlse.fr

457.   Address :– Residential

        68 rue des fontaines
        31300 Toulouse, France

        Telephone No. : (33) 5 61 59 12 71

        Fax No.   :

        e-mail: luc.mieussens@club-internet.fr

Selected publications:

[1] *Numerical comparison of BGK-models with proper Prandtl number,* (with H. Struchtrup), Phys. Fluids 16(8), 2797-2813 (2004)

[2] *Numerical comparison between two Spherical Harmonics Expansion models and a kinetic equation,* (with J.-P. Bourgade and A. Mellet), Mathematical and Computer Modelling, 40(7/8), 777-795 (2004)

[3] *A smooth coupling transition model between kinetic and hydrodynamic equations* (with P. Degond and S. Jin), J. Comput. Phys. 209, 665-694 (2005)

[4] *Implicit schemes for the Fokker-Planck-Landau equation.* (with M. Lemou), SIAM J. Sci. Comp. 27(3), 809-830 (2005)

[5] *Macroscopic fluid models with localized kinetic upscaling effects* (with P. Degond and J.-G. Liu), MMS 5(3), 940-979 (2006)

[6] *Numerical simulations of rarefied gases in curved channels: thermal creep, circulating flow, and pumping effect* (with K. Aoki and P. Degond), submitted (2007)

[7] *A moving interface method for dynamic kinetic-fluid coupling* (with P. Degond and G. Dimarco), submitted (2007)

[8] *A diffusion model for rarefied flows in curved channels* (with K. Aoki, P. Degond, S. Takata, and H. Yoshida), submitted (2007)

[9] *Uniformly stable numerical schemes for the Boltzmann equation preserving compressible Navier-Stokes asymptotics* (with M. Bennoune and M. Lemou), submitted (2007)

[10] *A new asymptotic preserving scheme based on micro-macro formulation for linear kinetic equations in the diffusion limit* (with M. Lemou) , submitted (2007)

510. Joint Collaborator(s) from India (Please attach biodata and list of not more than *10 MOST* relevant publications in the last five years) (Please use a separate sheet for each of the Joint collaborators)

511. Name and Designation   Prof. Phoolan Prasad, Honorary Professor, Department of Mathematics, Indian Institute of Science, Bangalore.

512. Sex   Male   [X]   Female   [   ]

513. Date of Birth   [0 | 1]   [0 | 1]   [1 | 9 | 4 | 4]
                          (Date)   (Month)   (Year)

514. Name of the Institution
Indian Institute of Science, Bangalore - 560012, India.

515. Name and Designation of the
Head of the Institution
Prof. P. Balaram, Director, Indian Institute of Science, Bangalore-560012, India

516. Address :– Institution
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Telephone No. : 91-80-2293-3205

Fax No.   : 91-80-23600146

e-mail : Prasad@math.iisc.ernet.in

517. Address :– Residential

No. 927-928, 7th Cross, HMT Layout, Mathikere, Bangalore – 560054

Telephone No. : 91-80-23371039

Fax No.   : -

e-mail:– -

Selected publications:

Book

1.   'Nonlinear Hyperbolic Waves in Multi-dimensions', Chapman & Hall/CRC, New York, May 2001 in 340 pages.

RESEARCH PAPERS WITH REPRINTS AND PREPRINTS

[1] Phoolan Prasad, An asymptotic derivation of weakly nonlinear ray theory, Proc. Indian Academy Sciences (Mathematical Sciences), 2000, 110, 4, 431-447.

[2] Monica, A and Phoolan Prasad, Propagation of a curved weak shock, J. Fluid Mechanics, 2001, 434, 119-151.

[3] Baskar, S and Phoolan Prasad, Kinematical conservation laws applied to study geometrical shapes of a solitary wave, Wind Over Waves II: Forecasting and Fundamentals. Ed. S. Sajjadi & J. Hunt, Horwood Publishing Limited, England 2003, 189-200. This is a proceeding for INI conference on water waves, Isaac Newton Institute, Cambridge, 28-31, August 2001 and WoW conference, Churchil College, Cambridge, 3-5 September 2001.

[4] Phoolan Prasad, Upstream propagating curved shock in a steady transonic flow, Proceedings IUTAM Symposium Transsonicum IV, 2-6 September, 2002, Goettingen, Germany; Ed. H. Sobieczky, Series "Fluid Mechanics and Applications", Vol 73; Kluwer Academic Publishers, Dordrecht-Boston-London, ISBN 1-4020-1608-5, (2003), 25-32.

[5] Baskar, S and Phoolan Prasad, Riemann problem for kinematical conservation laws and geometrical features of nonlinear wavefronts, IMA Journal of Applied Mathematics, 2004, vol 69, no 4, pp. 391-420.

[6] Baskar, S and Phoolan Prasad, 2005, Propagation of curved shock fronts using shock ray theory and comparison with other theories J. of Fluid Mechanics, 523, 171-198.

[7] Baskar, S. and Prasad, Phoolan, 2005, Kinematical conservation laws, ray theories and applications, Proc. of 10th International Conference on Hyperbolic Problems: Theory, Numerics and Applications, Osaka, Japan, September 13-17, 2004, Ed. F. Asakura, H. Aiso, S. Kawashima, A. Matsumura, S. Nishibata, K. Nishihara ; Vol. 1, 287-294, Yokohama Publishers.

[8] Baskar, S. & Prasad, Phoolan, 2006 Formulation of the problem of sonic boom by a maneuvering aerofoil as a one parameter family of Cauchy problems, Proceedings of Indian Academy of Sciences: Mathematical sciences, 116, 2006, 97-119.

[9] Baskar, S. and Prasad, Phoolan, 2005, Calculation of the front part of the sonic boom signature for a maneuvering aerofoil, presented at The 17th International Symposium on Nonlinear Acoustics (ISNA), Penn State University, USA, 18-22 July 2005. To appear in the proceedings of the symposium.

[10] Phoolan Prasad, 2006, Kinematical conservation laws, ray theories and applications. An invited article for publication in the Indian Journal of Pure and Applied Mathematics. To appear soon.

550. Joint Collaborator(s) from France (Please attach biodata and list of not more than *10 MOST* relevant publications in the last five years) (Please use a separate sheet for each of the Joint collaborators)

551. Name and Designation

Dr. Raphaël Loubère

552. Sex   Male | X | Female | |

553. Date of Birth | 2 | 8 | | 1 | 1 | | 1 | 9 | 7 | 4 |
                 (Date)   (Month)   (Year)

554. Name of the Institution
Université Paul Sabatier Toulouse 3

555. Name and Designation of the
Head of the Institution

Prof. J.-F. Sautereau

556. Address :– Institution
**Institut de Mathématiques de Toulouse,
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557. Address :– Residential

55 chemin Caillol
31620 Fronton, France

Telephone No. : (33) 5 61 74 73 68

Fax No.   : same

e-mail: loubere@free.fr

Selected publications:
[1]. *Material order independent interface reconstruction using power diagrams*, **S.P.Schofield, R.V.Garimella, M.M.Francois, R.Loubère** in press *International Journal for Numerical*

28

Methods in Fluids (2007)

[2]. *The Internal Consistency, Stability, and Accuracy of the Discrete, Compatible Formulation of Lagrangian Hydrodynamics*, **A. L. Bauer, D. E. Burton, E. J. Caramana, R. Loubere, M. J. Shashkov, and P. P. Whalen**, *J.Comp.Physics 218, Issue 2, pp.572-593, 2006*

[3]. *``Curl-q": A Vorticity Damping Artificial Viscosity for Lagrangian Hydrodynamics Calculations*, **E.J.Caramana, R.Loubere** *J.Comp.Physics 215, issue 2, pp.385-391, 2006*

[4]. *Convergence of repair algorithms in 1D*, **B.Despres, R.Loubere** *Int.J.Finit.Vol (2006)*

[5]. *The Force/Work Differencing of Exceptional points in the Discrete Compatible Formulation of Lagrangian Hydrodynamics*, **R.Loubere, E.J.Caramana** *J.Comp.Physics 216, issue 1 pp.1-18, 2006*

[6]. *The repair paragdim: new algorithms and applications to compressible flow*, **R.Loubere, M.Staley, B.Wendroff** *J.Comp.Physics 211, Issue 2, 2006, pp.385-404*

[7]. *A subcell remapping method for polygonal staggered grids*, **R.Loubere, M.Shashkov** *J.Comp.Physics 209, Issue 1, 2005, pp.105-138*

[8]. *Modeling of laser-plasma interaction on hydrodynamics scales: Physics developments and comparison with experiments*, **S.Weber *et al*** *Laser and particle beam (2004) 22, pp.189-195*

[9]. *A transport simulation code for Inertial Confinement Fusion (ICF) relevant laser/plasma interaction*, **S.Weber, P.H.Maire, R.Loubère, G.Riazuello, P.Michel, J.Ovadia, V.Tikhonchuk**, *Comp.Physics Comm. 168, 141-158 (2005)*

[10]. *A lagrangian Discontinuous Galerkin type method on unstructured meshes to solve hydrodynamics problems*, **R.Loubère, J.Ovadia, R.Abgrall**, *Int. J. Numer. Meth. Fluids, 44, Isssue 6, pp. 645-663 (2004)*

Certificates from the Heads of the Institutions of the Principal Collaborators from India and France

In order to result in effective, long lasting interactions between scientists of the two countries, it is desired that collaborative programmes supported by IFCPAR/CEFIPRA should correspond to scientific interests of all collaborating laboratories, and not only to those of isolated investigators from these laboratories. For this reason, heads of collaborating laboratories are requested to commit themselves, by verifying that the proposed programme corresponds effectively to a major interest of the group they are responsible for, and by indicating the amount of resources (in terms of recurring expenses, equipment and manpower) allocated to the project from their own budget.

Project Title:

(1) Certified that this institution agrees to the participation of_____(Name)

_____(Designation) in this Institution as

Principal Collaborator for the above project which is being submitted for support to the Indo–

French Centre for the Promotion of Advanced Research.

(2) Certified that the infrastructural facilities related to the project activity available in this

institution including equipment, manpower and other facilities, and all necessary

administrative support will be extended for the project.

(3) This institution assumes to undertake the financial and other responsibilities of the part of the

project work which will be conducted in this country.

Date: Name & Signature
                                                                                      of the Head of the
                                                                                         Institution

Place: Seal

**Certificates from the Heads of the Institutions of the Joint
Collaborators from India and France when they are not from the same institution as
the Principal Collaborators**

In order to result in effective, long lasting interactions between scientists of the two countries, it is desired that collaborative programmes supported by IFCPAR/CEFIPRA should correspond to scientific interests of all collaborating laboratories, and not only to those of isolated investigators from these laboratories. For this reason, heads of collaborating laboratories are requested to commit themselves, by verifying that the proposed programme corresponds effectively to a major interest of the group they are responsible for, and by indicating the amount of resources (in terms of recurring expenses, equipment and manpower) allocated to the project from their own budget.

Project Title:

(1)   Certified that this institution agrees to the participation of_____(Name)

_____(Designation) in this Institution as

Joint Collaborator for the above project which is being submitted for support to the

Indo-French Centre for the Promotion of Advanced Research.

(2)   Certified that the infrastructural facilities related to the project activity available in this

institution including equipment, manpower and other facilities, and all necessary

administrative support will be extended for the project.

(3)   This institution assumes to undertake the financial and other responsibilities of the part of the

project work which will be conducted in this institution.

Date: Name & Signature
                                                                                          of the Head of the
                                                                                             Institution

Place: Seal

Annexure D

General Area of the Proposal

Proposals can be made in any discipline of science and technology, provided they are original, collaborative and of high scientific quality. In addition, projects concerning emerging scientific fields, or related topics of common relevance to both countries, such as advanced research concerning water resources and quality of water, biotechnologies and information and communication technologies, will be considered with particular attention by the Scientific Council if they meet the above mentioned criteria

[X]	**01.**	*Pure and Applied Mathematics*
[ ]	**02.**	*Computer and Information Sciences*
[ ]	**03.**	*Life and Health Sciences*
[ ]	**04.**	*Pure and Applied Physics*
[ ]	**05.**	*Pure and Applied Chemistry*
[ ]	**06.**	*Instrumentation*
[ ]	**07.**	*Earth and Planetary Sciences*
[ ]	**08.**	*Material Sciences*
[ ]	**09.**	*Environmental Sciences*

[ ]   *Biotechnology*

[ ]   *Technology of Information & Communication*

[ ]   *Water Resources*

Annexure E

<div align="center">

CHECK LIST

(to be submitted alongwith the proposal)

</div>

The following check list has been included in the format so as to enable the scientists to submit proposals complete in all respects. **Only those project proposals which have been duly filled in, including this check list, and complete in all respects, will be considered.**

☐ Cover sheet signed by both the Principal Collaborators.

☐ Certificate on official letterhead from the Head of the Institution of the Indian Principal Collaborator.

☐ Certificate on official letterhead (entête) from the Head of the Institution of the French Principal Collaborator.

☐ Certificate on official letterhead from the Head of the Institution of each Joint Collaborator(s) who is not from the same institution as the Indian Principal Collaborator.

☐ Certificate on official letterhead (entête) from the Head of the Institution of each Joint Collaborator(s), who is not from the same institution as the French Principal Collaborator.

☐ Detailed Project Report in English (around 5000 words) with select bibliography.

☐ Summary of Project in French (around 1000 words)

☐ Biodata of the Indian Principal Collaborator containing, inter alia, academic qualifications & research experience along with a list of not more than 10 most **relevant publications for the last five years only.**

☐ Biodata of the French Principal Collaborator containing, inter alia, academic qualifications & research experience along with a list of not more than 10 most **relevant publications for the last five years only.**

☐ Biodata of each Joint Collaborator from the Indian side containing, inter alia, academic qualifications & research experience along with a list of not more than 10 most **relevant publications for the last five years only.**

☐ Biodata of each Joint Collaborator from the French side containing, inter alia, academic qualifications & research experience along with a list of not more than 10 most **relevant publications for the last five years only.**

☐ A list of other projects currently being handled by the Indian Principal Collaborator, giving titles of the projects, funding agency, quantum of funds, starting dates and duration. It is not enough to give the list of the projects being handled by the group or laboratory of the Principal Collaborator. We need the lists of projects in which the Principal Collaborator is directly involved.

☐ A list of other projects currently being handled by the French Principal Collaborator, giving titles of the projects, funding agency, quantum of funds, starting dates and duration. It is not enough to give the list of the projects being handled by the group or laboratory of the Principal Collaborator. We need the lists of projects in which the Principal Collaborator is directly involved.

☐ Two copies of Passport size photograph of the Indian Principal Collaborator.

☐ Two copies of Passport size photograph of the French Principal Collaborator.