SUMMARY

Ninth International Workshop on Measurement and Computation of Turbulent Nonpremixed Flames

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INTRODUCTION

The series of workshops on Measurement and Computation of Turbulent Nonpremixed Flames (TNF) is intended to facilitate collaboration and information exchange among experimental and computational researchers in the field of turbulent combustion. The emphasis is on fundamental issues of turbulence-chemistry interaction. In past workshops these issues have been explored through collaborative comparisons of measured and modeled results for a selected set of turbulent nonpremixed and partially premixed target flames burning H_2, CH_4 or CH_4/H_2 mixtures. Several participating research groups have strong interest in applying this same collaborative framework to a broader range of combustion modes and fuels. With the increasing importance of combustion LES as a modeling tool, there has also been discussion of the need to develop a more complete framework for LES validation. With these considerations in mind, TNF9 was organized as a planning process to identify priorities for collaborative research and future workshop activities over a 4-6 year time frame. Background for this planning process was also outlined in the TNF8 Summary, which is available online (http://ca.sandia.gov/TNF/8thWorkshop/TNF8.html).

TNF9 was attended by 82 researchers from 13 countries. Thirty-nine posters were contributed, with abstracts included in the proceedings. The agenda emphasized three challenges facing the turbulent combustion research community:

- Development and validation of modeling approaches which are accurate over a broad range of combustion modes and regimes (nonpremixed, partially premixed, stratified, and premixed).
- Extension of quantitative validation work to include more complex fuels (beyond CH_4) and fuel mixtures that are of practical interest.
- Establishment of a more complete framework for verification and validation of combustion LES, including quality assessment of calculations, as well as development and utilization of approaches which extract knowledge and understanding from comparisons of detailed experimental measurements with detailed simulations.

This summary briefly outlines highlights of presentations and discussion on these central challenges. Comments and conclusions given here are based on the perspectives of the authors and do not necessarily represent consensus opinions of the workshop participants. This summary does not attempt to address all topics discussed at the Workshop or to define all the terms, acronyms, or references. Readers are encouraged to consult the complete TNF9 Proceedings and also the summaries from previous TNF Workshops, because each workshop builds upon what has been done before.

Our overall goal is to accelerate the development of advanced combustion models that are soundly based in fundamental science, rigorously tested against experiments, and capable of predicting the behavior of a wide range of turbulent combustion modes and regimes. Toward this goal, our strategy is to expand the scope of the workshop, while simultaneously refocusing the collaborative process, by selecting a small number new fuels and flames that can serve as future targets for multiple modeling approaches.

The complete TNF9 Proceedings are available for download in pdf format from the Internet at www.ca.sandia.gov/TNF. The pdf file includes materials from the proceedings notebook that was distributed to workshop participants in Montreal, as well as additional materials (such as presentation slides) contributed after the workshop.

Several papers relevant to TNF9 topics and target flames were presented at the 32nd Combustion Symposium. Most of these papers may be found in the sections on turbulent combustion within the *Proceedings of the Combustion Institute*, Vol. 32.

ACKNOWLEDGMENTS

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AN IMPORTANT NOTE OF CAUTION

Results in this and other TNF Workshop proceedings are contributed in the spirit of open scientific collaboration. Some results represent completed work, while others are from work in progress. Readers should keep this in mind when reviewing these materials. It would be inappropriate to quote or reference specific results from these proceedings without first checking with the individual authors for permission and for their latest information on results and references.

HIGHLIGHTS OF PRESENTATIONS AND DISCUSSIONS

Challenges and Strategies for Model Development and Validation across Combustion Modes and Regimes

This session was coordinated by Pope, Masri, Barlow, and Lindstedt. Material to prompt discussion was presented in two parts: an overview of relevant modeling issues (Pope), including a proposed system to characterize general modes of combustion; and an overview of candidate experimental target flames and burners (Barlow). The major points from the presentations and subsequent discussion are summarized below.

As with most combustion research, the investigations of the TNF workshop are motivated by practical applications, such as gas turbines and internal combustion engines. The combustion involved in applications is usually multi-phase, multi-physics, and multi-scale, and always multidimensional. To make progress in this difficult area, both in understanding and modeling, TNF has concentrated on relatively simple flames (i.e., single-phase, non-premixed, statistically axi-symmetric and stationary), so that we can focus on the phenomena of turbulence-chemistry interactions. To the extent that some models have been successful in providing a quantitative description of these phenomena (e.g., in the piloted flames, and lifted flames in vitiated co-flows), it is time to take another step towards the complexity of applications. Accordingly, a challenge addressed at TNF9 was to identify experiments suitable for the development and validation of models which are applicable across modes and regimes of combustion. (Here we use “mode” to differentiate between premixed, non-premixed, etc., whereas the “regime” depends on Reynolds number, Damkohler number, etc.)

The development and validation of models depends crucially on experimental (and increasingly DNS) insights and data, and hence it is appropriate to consider at the outset the experimental configurations which determine the modes of combustion. The two simplest modes of combustion are premixed and non-premixed. In going beyond these extreme modes, two questions that arise are: How to characterize more general modes of combustion? And, how general does a model need to be, in order to be useful in applications?

At TNF9, a system was proposed to characterize general modes of combustion, depending on how many “supplies” (S) are involved, and whether the system is adiabatic (A) or non-adiabatic (N). The idealized premixed flame is formed from a single supply (S=1) formed from the complete mixing of fuel and air, and hence without heat loss it is designated 1A, or with heat loss 1N. Similarly the idealized non-premixed flame is 2A or 2N, with the two supplies being fuel and air. Other 2A flames include: lifted non-premixed jet flames (in which there is partial pre-mixing between the streams prior to combustion); piloted jet flames (in which the pilot originates from the mixing and combustion of a stream formed from the two supplies); and stratified flames (in which there is mixing between to streams that are each within flammability limits). An example of a 3A flame is the piloted premixed jet burner (Dunn, Masri & Bilger 2006), because it requires distinct supplies for the central jet, pilot, and vitiated coflow. The significant difference between a 2A and a 3A flame is that, in a 2A flame, familiar concepts from both non-premixed and premixed combustion can be applied, e.g., reaction progress variable, laminar burning velocity, a single mixture fraction, and scalar dissipation. (In general, S-1 mixture fractions are needed to describe the mixing between the streams.) The significant difference between adiabatic (A) and non-adiabatic (N) is that, in the former, enthalpy does not need to be represented explicitly, since it depends in a known linear way on mixture fraction.

Consensus views at TNF9 were:

- Many practical flames can be approximated as 2N (or sometimes 2A), and given the theoretical simplifications that they afford, 2A/N flames provide good targets for model validation.
- Some applications are 3A/N and hence such flames merit research.
- Few practical flames involve more than 3 streams, and hence 4A/N etc., should not be considered.

A combustion mode diagram was introduced for 2A/N flames (see Fig. 1). In the mixture-fraction-temperature plane, the diagram shows the fuel and oxidant supplies, the inert mixing line, the equilibrium line, and the rich and lean flammability limits, all of which depend solely on the properties of the two supplies. Homogeneous inflowing streams (e.g., fuel jet, pilot stream, air stream) are shown as points on the plane; whereas a stratified stream is shown as a line. The locations of the inflowing streams on this plot then characterize the mode of combustion.

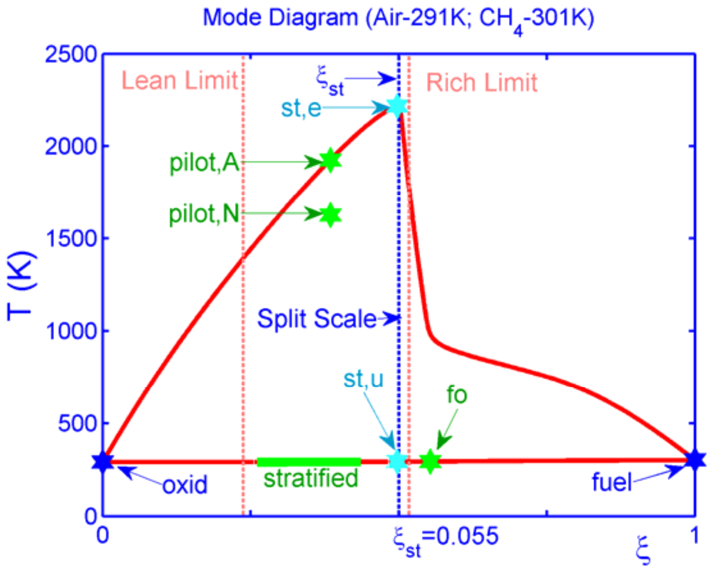

Figure 1. Diagram of 2A and 2N combustion modes.

Some turbulent combustion models are generally applicable, while others are limited in applicability to premixed, non-premixed, or 2A/N flames. In particular, models whose fundamental representations are based on species and enthalpy are generally applicable. (“Applicability” is distinct from, and does not imply, accuracy.) Such generally applicable models include: DNS, PDF, LES/FDF, RANS (with the neglect of species and temperature fluctuations), EDC, LEM and ODT. In contrast, models applicable to 2A flames are usually based on mixture fraction and progress variable; while, for 2N flames, enthalpy is added as a third variable. For general statistical models (e.g., PDF, LES/FDF) the challenges posed by more general modes of combustion are accounting for thin reaction zones and the effect of reaction to augment mixing. Both these challenges already exist in premixed combustion, and have been addressed in previous research – although questions remain. For models based on mixture fraction and progress variable (and possibly enthalpy), some of the challenges are: representing the joint PDF of the variables; consistently modeling the scalar dissipations; incorporating realistic combustion chemistry (beyond one- or two-variable parameterizations); and incorporating the effects of unsteadiness and scalar dissipation.

An overview of various burner configurations and experimental flames from the literature and from known work in progress was presented, and their suitability for use as TNF target cases was discussed. Most of the flames considered are 2A flames, and the discussion emphasized partially premixed and stratified flames. This emphasis was predicated on the assumptions that:

- The TNF Workshop will continue to be centered on issues of turbulence-chemistry interaction in atmospheric pressure flames of relatively simple fuels.
- Work will continue on some of the established nonpremixed target flames and burner geometries. (For example, established flames and burners are expected to be used in the context of LES quality assessment and extension of experiments to more complex fuels.)

For the purpose of this summary, stratified flames are those where the primary mode of combustion is propagation of a turbulent reaction zone through non-uniformly mixed, flammable reactants. Partially premixed flames, such as lifted jet flames, allow for mixing across the full mixture fraction range prior to reaction. Thus, partially premixed flames can admit a combination of combustion modes within one burner, including edge flame propagation, diffusion flame burning, and auto-ignition, if mixed temperatures are sufficiently high.

Figure 2 was used to illustrate qualitatively the combustion modes and regimes represented by existing TNF target flames and other flames that might serve as future targets. Brief descriptions and references are provided in the TNF9 Proceedings. Desirable characteristics of validation target flames were also outlined, as listed in the proceedings. In addition to discussion during the full session on Friday morning of the workshop, additional smaller group discussion took place on Friday afternoon to identify new target flames and action items.

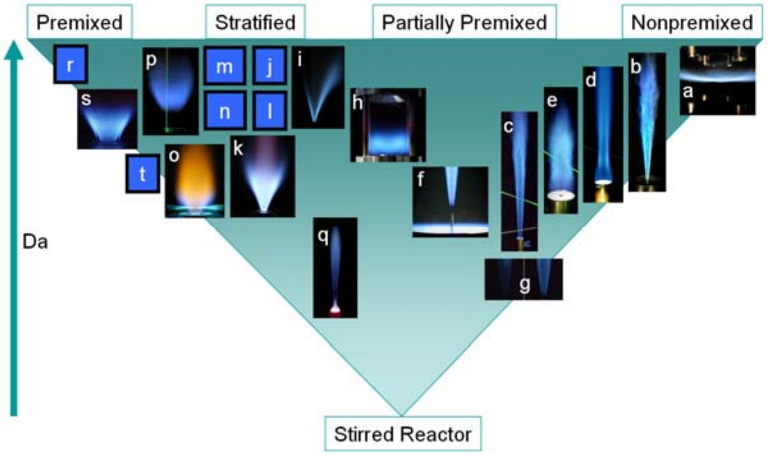

Figure 2. Qualitative map of combustion modes with various laboratory-scale flames investigated by TNF Workshop participants or reported in the literature. Letter designations refer to a table in the full proceedings, which also includes brief descriptions and references for newly considered cases.

Summary of points on partially premixed flames:

1. The DLR model gas turbine combustor has been measured extensively and appears to be a rich problem in terms of combustion modes. However, the complexity of the inflow passages, especially for methane injection, was considered a significant disadvantage, so this burner will not be used as a target case for the next TNF Workshop. Future consideration is possible.
2. There is still significant interest in the lifted jet flames in hot coflow. Data on these flames is still somewhat limited in comparison to the DLR jet flames or the Sandia piloted flames, for example. The Sydney group will review and consolidate their data on these flames, and interested parties will discuss the possibility of generating a ‘standard’ burner design and building multiple copies of that design.
3. Sensitivity of these flames to variations in computational boundary conditions, combined with experimental uncertainty in measured boundary conditions was one item of concern. Coflow composition was identified as a sensitive parameter, in addition to coflow temperature. The Cornell group performed calculations illustrating this sensitivity, and results are included in the proceedings.

4. The suggestion was made that an interesting validation test series would include a parametric progression across the transition from flame propagation to auto-ignition being the main stabilization mechanism.
5. It is hoped that specific cases for collaborative comparisons on this flame geometry will be agreed upon quickly, so that multi-model comparisons may be performed at the next TNF Workshop in 2010.

Summary points on stratified and premixed flames are as follows:

6. Among several stratified burners considered, the TU Darmstadt stratified burner (labeled k in Figure 2) attracted the most interest. Data are not yet available, but velocity measurements have been complete on several flames (see poster abstract by Seffrin et al.), and the group hopes make velocity data and some scalar results available in time for collaborative model comparisons at the TNF10 Workshop.
7. Any stratified flame experiments should include a premixed baseline case or cases, so that particular effects of stratification may be identified and the corresponding models tested. Within the context of the TNF Workshop, it is anticipated that premixed flames will be addressed as baseline cases for stratified burners. Accordingly, no cases of purely premixed combustion were seriously considered.
8. Stratified combustion experiments at low turbulence levels, such as V-flame experiments, were recognized as useful from a fundamental perspective and for comparison with DNS but less interesting for the purpose of turbulent combustion model validation within the TNF framework.
9. The TECFLAM swirl flame and the TU Darmstadt version of the Cheng low-swirl burner (o and p in Figure 2) each burn as premixed flames near the burner center. However, due to air entrainment in these open geometries, the flame propagates through stratified mixtures at the outer edges. The complexity of the inflow geometries of these cases made them less appealing to modelers within this group than the new co-annular burner.
10. A few groups will continue to work with the Sydney Piloted Premixed Jet Burner (q in Figure 2). This is a 3-stream problem (3A) and cannot be addressed by some of the methods of interest.
11. We will stick with methane as the fuel of choice for this first push into stratified combustion.

Another point common to both types of flames is that it will be useful to have some preview calculations performed ahead of the general data release. This should provide insights on various aspects of the problem that may be beneficial to other modelers.

Extension of Validation Work to More Complex Fuels

The session on the extension of validation to more complex fuels was co-ordinated by Lindstedt with contributions made by Barlow, Bourque, Law, Chen (J.H.) and Chen (J.Y.). The topics addressed included practical needs, development directions for simplification methodologies, and an assessment of the ability of both DNS and experimental research to contribute to the process. The further development and application of methods for mechanism construction and reduction are not covered in the current summary. Rather, the focus is on reporting the outcome of the discussions held at the workshop and on making recommendations for a route towards more extensive validation of computational methodologies.

A range of aspects of relevance to the inclusion of more complex fuels (or fuel blends) were discussed in a breakout session. Agreement was reached on several points that form a route towards the gradual introduction of more complex fuels.

1. The introduction of heavier hydrocarbon blended with methane was identified as a key factor in practical applications. The consequences include a direct impact on the auto-ignition limit and hence on the permissible residence time used as part of premixing devices in gas turbines. The allowable amount of heavier hydrocarbons can be expected to depend on the amount of inert material, but is likely to be of order 10%. If the heavier hydrocarbon component is initially treated as a C_2 species, then it can be expected that current reduced chemistry models can be (comparatively) readily adjusted to cover such compositions. The further development of reduced models for heavier hydrocarbons is currently being pursued using a range of methodologies. It is anticipated that accurate detailed and reduced models for fuels such as n-heptane, which exhibit a negative temperature coefficient (NTC) region, will become more generally available in the medium term. The group initially identified the Cabra (jet in hot coflow) and Sandia/Sydney piloted burner geometries as suitable for experimental studies of (i) auto-ignition in a turbulent flow field and (ii) the impact of higher hydrocarbons on local extinction/re-ignition. The latter could, for example, take place in a Flame E/F equivalent. The suggested timescales would be the initial use of C_1/C_2 mixtures over a 1 to 3 year period with the addition of higher hydrocarbons, such as C_3/C_7, over a period of 3 to 6 years.

2. The second item discussed at some length covered the importance of more hydrogen and/or carbon monoxide and/or carbon dioxide rich fuel streams. Specifically, hydrogen rich fuel streams may arise in the context of carbon sequestration technologies and through the use of process gas from chemical industries. The presence of large amounts of carbon dioxide is common in biogas derived from reactors or landfill. It is arguable that such mixtures do not fall into the category of more complex fuels, but rather present an evolution of what is currently being done (or has been done) through the consideration of fuel mixtures of relevance to sustainability driven technologies. From such a point of view, it would make sense to explore the interest of the TNF community to consider such mixtures. A comparatively recent study of localized extinction in high Reynolds number CH_4/H_2 flames has been made at Sandia (Lindstedt *et al.*, Proc. Combust. Inst. 31 (2007) 1551-1558) and a write-up of the experimental data is almost complete (Barlow *et al.*, to be submitted). Other past studies have covered mixtures with carbon dioxide and carbon monoxide, and it is suggested that current data sets be reviewed and that the topic be revisited should a consensus be reached by a group of interested investigators.

3. A strong interest in a comparative study of oxygenated (bio-derived) fuels was recorded. A specific suggestion was made that the different properties of ethanol and dimethyl ether could result in a potentially ideal study of the impact of octane/cetane numbers on auto-ignition and local extinction/re-light in turbulent flames. The flames where such effects could be studied include the jet in hot coflow (Cabra) and piloted jet (Sandia/Sydney) geometries discussed in Item 1 above. Further advantages of this route include a modest extension of the chemical complexities, direct practical relevance, and the anticipated comparatively modest additional experimental difficulties. Given the focus on turbulence-chemistry interactions in the TNF workshop community, it was suggested that the fuels should be pre-vapourized.

4. The issue of moving towards transportation fuels via the blending of increasing amounts of fuels such as n-heptane with methane was also discussed. The experimental challenges that such a step would entail are likely to be significant and it is recommended that a stepwise approach is taken as the quality of the data produced must not be significantly adversely affected.

5. The need for much better data featuring incipient and/or actual soot formation was also discussed at length. The problem is experimentally exceptionally challenging and there is an increasing possibility that DNS studies may provide additional information. The issue of soot formation is, despite the intrinsic difficulties, ideally suited to the TNF community due to the importance of turbulence-chemistry interactions caused by both the slow formation and oxidation chemistries. It is also probable that suitable flames could be formulated by increasing the amount of ethylene in methane along with residence time variations through changes in the Reynolds number.

In addition to the above points, it was emphasised that DNS studies of combusting flows are approaching the point where complex fuels are addressed. Specifically, data may be produced that directly complements experimental studies. The topics that can be covered include flame stabilization mechanisms and the relative roles of auto-ignition and flame propagation at the base of lifted flames. It is also likely that the fuels mentioned above (e.g. hydrogen, ethylene, methane, dimethyl ether, ethanol and n-heptane) will be accessible. A direct consequence is the potential for synergies in submodel development for such fuels.

The following recommendations are made for advancement ahead of TNF10.

6. Study the impact of the gradual addition of heavier hydrocarbons on auto-ignition and extinction/re-light as outlined in Item 1 above.

7. Study the impact of fuel structure through the use of DME and ethanol as outlined in Item 3 above.

Finally, it is recognised that increased levels of partial premixing may have to be used to mitigate experimental difficulties associated with the use of more complex fuels. From a practical perspective, such a development is not likely to be limiting, though it may impact the applicability of more classical modelling approaches. However, it is likely that both recommended items will have direct practical application and as such the use of additional flame geometries would be beneficial.

LES Quality Assessment

Following recommendations from TNF8, Andreas Kempf and Joe Oefelein coordinated a session aimed at formalizing quality assessment techniques for LES in the context of the TNF target flames. The goal was to establish a starting point for the progressive incorporation of quality assessment in future calculations.

The session opened with an invited talk by Bernard Geurts (Universities of Eindhoven and Twente, The Netherlands) on interacting errors in LES. The presentation showed how modeling errors and numerical errors can partially cancel one another, leading to a situation where less numerical error could lead to a less accurate prediction – or alternatively, where better sub-grid models could also lead to a less accurate prediction. The “error-landscape” approach was also presented, where a single error-quantity is presented as a function of grid-resolution and an independent model parameter. The error landscape shows that an optimum exists for the value of the model parameter, at least for decaying homogenous isotropic turbulence. If the Smagorinsky model is used, the optimum model parameter C_s was shown to decrease with grid refinement to the point where a DNS is obtained with $C_s=0$.

A comparison of model calculations and experiments for the Sydney Bluff Body Flames was coordinated and presented by Andreas Kempf. Emphasis was placed on LES quality, quality indices, predictability, and sensitivity of the flow. Contributions from ANSYS (Goldin), Darmstadt (Hahn, Olbricht, Janicka) and Imperial College (Kempf) were shown using 625 thousand to 40 million cells. Predictions of velocity and mixture fraction fields varied but were reasonable for all contributions with at least 1-million cells. Comparable results were obtained with a commercial CFD code (ANSYS) on partially unstructured grids with a block-structure research code (FASTEST, Darmstadt), and with a research code using equidistant meshes (PsiPhi, Imperial). The flames were found to be relatively sensitive to boundary conditions, and as a consequence a, discussion evolved about detailed boundary conditions for LES, what level of detail can be realistically expected, and how sensitive a relevant test-flame should (or should not) be. The issue of boundary conditions and the related sensitivities will be an ongoing topic at future workshops.

As part of the analysis of the Sydney Bluff Body Flames, Goldin (ANSYS) and Kempf (Imperial) provided data from LES-quality indicators, like the estimated resolved turbulent kinetic energy or Celik's LESIQ method based on different grids and turbulent viscosity. This was similar to Geurt's approach. Conceptually, these indicators can help quantify the quality of an LES. However, none of the indicators considered provided a suitable measure of a well resolved LES. Indicators based on turbulent viscosity rely on the subgrid-model, which itself is only accurate if the resolution is sufficiently fine and the numerical method is non-dissipative. Otherwise, these models may under-predict the unresolved fluctuation, falsely implying that the simulations resolve most of the fluctuations. A key outcome of the comparisons was that the methods proposed for quantification of LES accuracy are still in their early development. Examples presented demonstrated that the formal development and application of quality assessment techniques has a lot of potential, but will require systematic research over the next several workshops to refine. The recommendation was that we continue to integrate quality assessment techniques with the progression of target flames being considered and work toward using the techniques to assist in quantifying the errors associated with LES and the respective models and numerical methods used.

A talk by M. Ihme examined the sensitivity of LES noise calculations to LES accuracy. Combustion induced noise strongly depends on the instantaneous heat release rate. Thus, this quantity must be modelled very accurately, which is only possible if subgrid-scale mixing and chemical kinetics are well understood. Accurate treatment of combustion noise will ultimately be a very difficult test for LES accuracy.

G. Goldin of ANSYS presented his simulations of the Sydney Bluff Body flames, before presenting a new ANSYS feature to analyse sensitivities. The new version of the code can calculate how changes in any selected parameter would affect the flow at a given point, shedding more light on flow-sensitivity and instability.

Issues and Examples for Comparing Experiments and LES

The development of predictive LES capabilities for a wide range of turbulent combustion conditions requires the development and validation of subgrid scale models and experimental verification of resolved-scale dynamics. Comparisons between measured and modeled statistics need to be expanded beyond matching mean and rms profiles. To date, the TNF Workshop has primarily focused on using point and line measurements for comparisons with models, and 2-D imaging measurements have remained a largely untapped resource. The coupling of imaging diagnostics and LES enables comparisons between measured and modeled physical structures in turbulent flames. Imaging measurements provide insight into spatial and temporal correlations, which can be compared with LES calculations on a statistical basis. Recent high-resolution 1-D and 2-D measurements can be used to evaluate resolution requirements, provide guidance for LES filter sizing, and develop subgrid scale models. However, a number of fundamental issues must be addressed before quantitative information can be extracted from comparisons of imaging measurements and LES. The TNF Workshop can play a central role in establishing a framework for these comparisons.

Jonathan Frank, Joe Oefelein, and Andreas Dreizler organized a session that highlighted issues for comparing measurements and simulations of spatial structures and temporal evolution of turbulent flames and non-reacting flows. The first section focused on measurements of thermal dissipation structures in flames. Considerations for LES included the variation of turbulence levels and dissipation length scales with temperature, the anisotropy of the dissipation structures, and the relatively sparse sampling of dissipation layers within a typical LES grid cell.

The second section highlighted the effects of LES filter size on modeling the dynamics of scalar mixing in a turbulent non-reacting jet. Comparisons of measurements and LES of non-reacting flows isolate the passive scalar mixing problem from the effects of chemical reactions and heat release in flames. Preliminary results demonstrated that temporal damping and dispersion can significantly alter the spatial evolution and structural similarities of the filtered dissipation structures relative to the actual dissipation field. LES of passive scalar mixing must be better understood in the course of validating LES of flames.

The final section of the presentation described current diagnostic capabilities and sampling requirements for time-series measurements as well as the possibility of using Taylor’s hypothesis to convert time-series measurements to pseudo 3-D measurements (see poster abstract by Gamba, Clemens, Ezekoye). Examples included PIV and PLIF measurements in turbulent counterflow and jet flames. Recent advances in high-repetition rate detectors and lasers provide relatively high sampling rates. However, the current state-of-the-art equipment does not meet all of the demands for recording the temporal evolution of TNF flames. The sampling-rate requirements depend on the quantity being measured and the location in the flame. The inclusion of time-history effects in comparisons between measurements and LES presents a number of challenges. The interpretation of 2-D imaging measurements is complicated by out-of-plane motion. Comparisons require conditional sampling of the measurements and simulations. For example, measurements of localized flame extinction could use a coordinate system that is referenced to the location of initial extinction.

Discussion points for comparing experiments and LES:

- Consistency in spatial and temporal averaging of experiments and LES
- Systematic method for choosing LES filter sizes
- Sensitivity of subgrid models to turbulence anisotropy and to low local Reynolds numbers in high-temperature regions
- Extension of results from current TNF flames to higher Reynolds number flames that have less overlap of the energy and dissipation spectra

- Methods for comparing measured and simulated physical structures of turbulent flames on a statistical basis
- Applicability of knowledge from LES of turbulent non-reacting flows to turbulent flames
- Applicability of Taylor's hypothesis for enabling pseudo 3-D measurements
- Limitations of spatial and temporal resolution for measurements at high Reynolds numbers

Priorities and Planning for Future Work and TNF10 (2010)

The 33rd Combustion Symposium will be held at Tsinghua University in Beijing, China, August 1-6. It is likely that TNF10 will be held just before the Symposium in the same part of the world.

There is ongoing work on modeling of existing TNF target flames, using new or improved submodels or new modeling approaches. There will also be ongoing work on LES quality assessment and methods for comparing experiments and LES. Much of this can be done based on experimental data that already exist. Movement into the new challenges of validating models for flames that extend across different modes and regimes of combustion will require new experimental data sets. Highest priorities related to these new directions are:

- Completion of initial experiments on the TU Darmstadt stratified burner and selection of specific target cases. It is hoped that boundary conditions, key experimental results, and initial guidelines for calculations and comparisons will be available for distribution before the end of 2009. Another discussion point was that preliminary calculations may be used to help establish a well posed problem for calculation by multiple groups.
- Completion of exploratory experiments to evaluate the potential to extend current multiscalar measurement techniques to investigate turbulent flames with hydrocarbon fuels more complex than CH_4. TU Darmstadt and Sandia will be conducting collaborative experiments during early 2009. A variety of flows and flames with ethane, ethylene, propane, and dimethyl ether will be considered. Prospects for turbulent flame measurements using the piloted jet burner or the lifted flame in hot coflow will also be evaluated at that time.
- Consolidation by the Sydney University group of data on lifted flames in hot coflow and Joint consideration by several groups of the possible construction of a set of identical burners for collaborative studies on this type of flame.

Discussion of progress and refinement of target flame priorities for TNF10 should take place during the first half of 2009.