

Detonation in Mixtures of JP-10 Vapor and Air

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An experimental study of the detonation properties of the high molecular weight aviation fuel JP-10 was performed. Detonation cell size measurements for mixtures of JP-10 vapor and air at elevated initial temperatures are reported. Experiments are performed in a 6.2-m-long, 10-cm inner-diameter heated detonation tube at an initial mixture pressure of 2 atm and initial temperatures of 373, 473, and 528 K. The first half of the tube is equipped with turbulence producing orifice plates. Flame acceleration leads to detonation initiation within the first 2 m of the orifice-plate-laden part of the tube, and a detonation wave propagates in the smooth second half of the tube. The detonation cellular structure is recorded on a soot foil inserted into the end of the tube. The detonation velocity measured just before the foil is within 1 to 2% of the theoretical Chapman–Jouget velocity. The detonation cellular structure for off-stoichiometric mixtures was found to contain substantial substructure. The average cell size is obtained by measuring the transverse distance between parallel diagonal tracks scoured onto the foil. It was found that to within the measurement uncertainty the cell size changed very little over the temperature range tested. The measured deflagration-to-detonation transition composition limits are found to correlate well with the classical detonation propagation criterion based on the detonation cell size λ and the orifice plate diameter d , that is, $d/\lambda \geq 1$. The measured JP-10 vapor air mixture cell size is correlated with the calculated Zeldovich von Neumann Döring (ZND) induction length for propane air mixtures with similar stoichiometry.

I. Introduction

THE single-component hydrocarbon fuel known as jet propellant 10 (JP-10, chemical formula $C_{10}H_{16}$) is currently used in many military aviation applications and is generally considered the fuel of choice for pulse detonation engines (PDE).¹ JP-10 has been used extensively in PDE prototype testing.² A PDE is a propulsion device that operates cyclically based on the detonation mode of combustion. Interest in PDEs has escalated in the last two decades with research programs ongoing worldwide.³ Essentially, the PDE cycle consists of a fuel-air mixture charging stage, detonation initiation and propagation stage, and ending with a combustion products blowdown stage. During the charging stage, any combustion products remaining in the combustor after blowdown are displaced out the exhaust. Clearly for this cycle to occur, a detonation wave must be able to propagate through the fresh fuel-air mixture loaded into the combustor. As a result, knowledge concerning the detonation wave properties of the fuel-air mixture is essential for the design of the combustor.

Classically, a detonation wave is described as a one-dimensional complex consisting of a leading shock wave followed by a reaction zone propagating at a steady velocity. This detonation structure is commonly referred to as the Zeldovich von Neumann Döring (ZND) structure. The shock wave and the reaction zone are coupled and propagate at a unique velocity, called the Chapman–Jouget (CJ) detonation velocity, which depends on the mixture energy content and the mixture initial pressure and temperature. Energy is released behind the shock wave as a result of chemical reactions initiated by adiabatic shock heating. The coupling between the gasdynamics and the energy release is nonlinear as a result of the strong sensitivity of the reaction rate to temperature. As a result, the one-dimensional ZND detonation structure is unstable.⁴ This instability is manifested

in terms of a shock velocity that oscillates about the CJ detonation velocity.⁵ The detonation structure is also unstable to transverse perturbations. In reality, a detonation has a complex three-dimensional structure consisting of multiple shock waves and discrete reaction zones.⁶ The detonation consists of a corrugated shock front moving in the primary direction of the detonation wave and finite-amplitude shock waves propagating transversely to the shock front. This detonation front structure is essential for self-sustained propagation.

The multidimensional structure of a detonation front can best be described by the time history of the local interaction between the various shock waves and reaction zones. The schematic in Fig. 1 shows the nonplanar leading shock wave and the transverse propagating shock waves. Also shown are the distributed reaction zones that follow the leading shock waves. In two dimensions the three shock waves intersect at the triple point, which moves transversely across the front as it propagates forward. Also part of the three-shock structure, but not shown in the schematic, is a shear layer emanating from the triple point back into the combustion products. The trajectory of adjacent triple points over time defines a “cell” with transverse width λ (see Fig. 1). In the schematic the shock and reaction zone positions are shown within the cell at two earlier times. The shock-wave strength decays as it propagates across the cell length, and as a result the induction time and consequently the reaction zone length increase, as shown in Fig. 1. For a theoretical detonation wave the average shock velocity over the length of the cell is equal to the CJ velocity. In the first half of the cell, the shock propagates at a velocity higher than the CJ velocity, and at the end of the cell the shock propagates well below the CJ velocity. By the end of the cell, the shock and reaction zone can be effectively decoupled in a hydrocarbon-air mixture.⁷ If decoupling occurs, the detonation is regenerated in the subsequent cell as a result of the local “explosion” that occurs at the apex of the cell in the region of the adjacent transverse-wave collision.

The cell width, referred to as the cell size in the remainder of this paper, is measured experimentally by the soot foil technique. A flexible piece of sheet metal is coated with carbon soot on one side and inserted into the back end of the tube with the sooted side of the foil facing the tube centerline. As the detonation wave propagates across the sooted surface, a cellular, or “fish-scale”-like, pattern is scoured onto the foil. The pattern tracks are produced by the interaction of the detonation front triple points and the soot particles on the foil. The foil tracks correspond to the trajectories shown in Fig. 1. In general for fuel-air mixtures the cellular pattern is very irregular, and typically a large sample of measurements is taken over the

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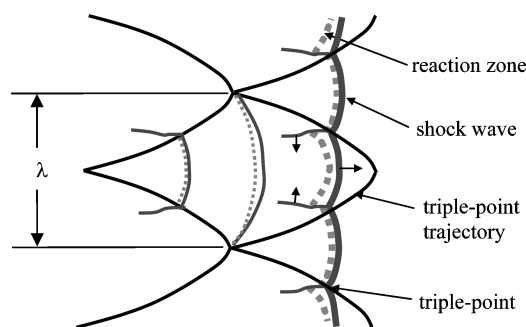


Fig. 1 Schematic showing the detonation front structure consisting of multiple shock waves and reaction zones.

foil, and the average value is reported. The scatter in the detonation cell size data can be as much as 50% of the average value. For certain fuel-air mixtures the cellular pattern can be further complicated by substructure consisting of smaller scale cells inside the major cells.⁸ Typically the cells size is measured manually directly from the foil. A certain amount of interpretation of the pattern is required, especially if substructure is present, before the measurements are made. This introduces uncertainty into the measurement. To remove this measurement bias, Shepherd et al.⁹ used image processing and statistical analysis to measure the average cell size and the scatter.

The detonation cell size has been proposed as a fundamental detonation length scale that can be used to characterize the detonability of a gaseous explosive.⁶ Most detonation phenomena can be correlated with the detonation cell size. For example, it has been shown that for a detonation wave to propagate in a tube the inner diameter must be greater than or equal to the detonation cell size. From experiments investigating deflagration-to-detonation transition (DDT) in an orifice plate laden tube it was shown that DDT only occurs if the orifice plate diameter can accommodate at least one detonation cell, that is, $d/\lambda > 1$ (Ref. 10). Therefore, detonation cell size data are very important for the design of a PDE combustor operating with a certain fuel-air mixture at a given initial pressure and temperature.

Most experimental studies performed to date looking at PDE phenomena have used smaller hydrocarbon fuels that are gaseous at room temperature. This is primarily done in order to avoid the difficulties of creating a uniform fuel-air mixture using liquid fuels injected directly into the combustor.² There is an abundance of cell size data in the literature for smaller hydrocarbon fuels as well as hydrogen.^{6,11} However, for PDE applications liquid fuels such as JP-10 are more attractive because they have a higher energy density and provide increased safety when handled and in storage. Only limited cell size data exist in the literature for JP-10 fuel. Akbar et al.¹² used a 30-cm tube to measure the detonation cell size of a stoichiometric mixture of JP-10 vapor and air at initial temperatures of 408 and 503 K and at initial pressures of 155 and 210 kPa. Austin and Shepherd¹ used a 20-cm-diam tube to measure cell size in JP-10 vapor air mixtures over an equivalence ratio range of 0.7 to 1.4 at an initial temperature of 353 K and an initial pressure range of 20 to 130 kPa. In this investigation the detonation cell size is measured in JP-10 vapor/air mixtures as a function of mixture composition and initial pressure and temperature.

The transient analysis of a one-dimensional CJ detonation wave performed by Fickett and Woods⁵ using a simple one-step reaction showed that the coupling between the lead shock wave and energy release is unstable as predicted by Erpenbeck's analysis.⁴ The simulation demonstrated that the lead shock velocity oscillates about the CJ detonation velocity at a fixed frequency. As the mixture effective activation energy is increased, thereby increasing the reaction-rate sensitivity to the lead shock strength, higher mode instabilities appear. The results from this analysis are of fundamental importance to understanding actual detonation phenomena. However, the results cannot be used to directly predict the detonation cell size. To predict detonation cell size for a given combustible mixture, a multidimensional simulation with realistic chemistry must be performed. Such numerical simulations of a propagating detonation wave are compu-

tationally challenging because of the large range in time and spatial scales. The first studies were limited to two-dimensional detonation waves using single-step reactions. Oran et al.¹³ performed simulations of two-dimensional detonation waves with realistic chemistry for the hydrogen-oxygen system. One would expect that with current massive parallel computing capabilities full three-dimensional detonation simulations with realistic chemistry will be forthcoming.

Because of the inability to predict detonation cell size, it has become common practice to correlate the measured detonation cell size with the ZND detonation induction length Δ (Refs. 14 and 15). This approach is considered highly idealized because it does not take into account the dynamics between the leading shock wave and the reaction zone. The ZND approach is a simple method used to extrapolate existing detonation cell size data and does not represent a physical model of a detonation wave. The steady-state one-dimensional conservation of mass, momentum, energy, and species equations are integrated using the CJ state as the boundary condition. Because the flow Mach number asymptotically approaches unity as heat is released, the induction length is typically defined based on the temperature profile of the reaction zone. Shepherd¹⁵ defined the induction length by the location in the reaction zone where the energy release rate is maximum. This corresponds to the location where the temperature gradient in the reaction zone is maximum. Shepherd¹⁵ also proposed that it can be assumed that after the leading shock a particle passing through the reaction zone undergoes a constant volume adiabatic explosion process. By this approach the ZND induction length can be obtained by multiplying the induction time, based on the postshock pressure and temperature, by the postshock particle velocity relative to the shock wave. Typically a linear relationship between the induction length and the detonation cell size is used, for example, $\lambda = A\Delta$, where A is the proportionality constant.

To calculate the ZND induction length Δ , a reaction mechanism is required. For small hydrocarbon fuels the reaction mechanism by Konnov¹⁶ can be used for detonation calculations.¹⁷ Because of the large size of the JP-10 molecule, a complete description of its decomposition and combustion is challenging. A mechanism consisting of 174 elementary reactions among 36 chemical species was developed by Li et al.¹⁸ The mechanism adds 27 steps to an earlier system developed for smaller hydrocarbons (C_1 - C_3 species). A comparison of predictions made with the mechanism to experimental shock-tube ignition delay data for JP-10/oxygen/argon up to a pressure of 8 bars shows fair agreement. Experimental JP-10/air ignition delay data obtained by Mikolaitis et al.¹⁹ show a strong pressure effect. As a result, as with other mechanisms the Li et al.¹⁸ mechanism might not be as accurate at the significantly higher pressures associated with detonation waves, for example, 40–50 atm.

In this study the detonation cell size in mixtures of JP-10 vapor and air at 2 atm and initial temperatures up to 528 K is measured experimentally. The cell size measurements are then correlated using the ZND model induction length.

II. Experimental Detail

The experiments were performed in a 6.2-m-long, 10-cm-inner-diameter heated detonation tube. The first half of the tube is filled with 0.43 blockage ratio (BR) orifice plates equally spaced at one tube diameter. $BR = 1 - (d/D)^2$, where d is the orifice plate diameter and D is the inner diameter of the tube. A schematic of the experimental apparatus is provided in Fig. 2. The test mixture is prepared by method of partial pressures in a separate mixing chamber that is equipped with a pneumatic-motor-driven propeller for mixing the constituents. The mixing chamber is maintained at a temperature between 383 and 403 K to avoid JP-10 condensation. A vacuum pump is used to evacuate the mixing chamber to a pressure below 0.4 kPa, and then liquid JP-10 is introduced into the mixing chamber. The vapor pressure of the JP-10 at 385 K is roughly 10 kPa. Air is then added to the mixing chamber to a final pressure between 360 and 380 kPa, depending on the desired mixture composition. The mixture is loaded into the preheated, preevacuated detonation tube. The mixture is heated to the test temperature during transport through heat-traced 1.27-cm-diam tubing connecting

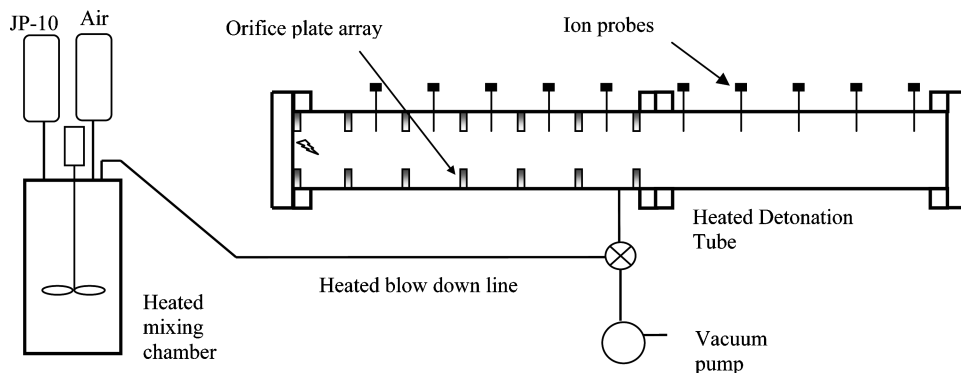


Fig. 2 Experimental apparatus schematic.

the mixing chamber and the detonation tube. Because the mixture is prepared in the mixing chamber at a relatively low temperature, there is no concern for dissociation of the fuel during mixing. The mixture is present in the detonation tube at the test temperature for no more than 15 s before ignition. Combustion is initiated at one end of the tube via a standard automobile spark ignition system. The average flame velocity is obtained from time-of-arrival measurements made using ionization probes located along the length of the tube, typically spaced at 30.5 cm.

Detonation cell size is measured using a soot coated 0.5-mm-thick aluminum sheet. Two different size sheets were used: 30.5×30.5 cm for the most reactive mixtures and 30.5×61 cm for the less reactive mixtures. Each sheet is rolled into a 15-cm-diam cylinder, and the inside surface is coated with Dow Corning DC 200 silicone oil with a 10-centistroke viscosity. The inside surface of the foil is then coated with soot via a kerosene flame and inserted into the test vessel. After the experiment the foil is pulled from the tube and unrolled for analysis. The foil is sprayed with a clear lacquer to preserve the inscribed cellular pattern. A thin Mylar sheet is taped to the sooted side of the foil, and the cellular pattern is traced using permanent marker.

III. Results and Discussion

A. Flame Acceleration and DDT

For each fuel–air mixture, the flame velocity down the length of the tube was measured at initial temperatures between 373 and 528 K and at an initial pressure of 2 atm. Experiments performed at an initial pressure of 1 atm did not result in DDT for any initial temperature. Shown in Figs. 3–5 are the average flame velocities measured along the length of the tube for various mixture compositions at 2 atm and at different initial temperatures. In general the flame accelerates in the first couple of meters under the influence of the orifice plates. If DDT occurs in the first half of the tube, a detonation wave propagates at a velocity of about 1500 m/s up to the last orifice plate located at 3.1 m from the ignition end. This velocity is substantially below the CJ detonation velocity, which is roughly 1900 m/s for the mixture range tested, as a result of heat and momentum losses to the orifice plates. For mixture compositions where a detonation is initiated, the detonation velocity jumps after exiting the orifice plate laden first half of the tube to within 1 to 2% of the mixture CJ velocity. If DDT does not occur, the flame velocity approaches a value just below the speed of sound of the combustion products, roughly 900 m/s, within the orifice plate laden first half of the tube. After exiting the orifice-laden part of the tube at 3.1 m, the flame velocity decays. This decay in velocity occurs because of the loss of orifice-plate-generated turbulence in the unburned gas ahead of the flame. In general DDT occurs within the orifice-plate-laden part of the tube. In some tests detonation initiation occurred at the transition point from the orifice-filled part of the tube to the smooth part of the tube. An example of this is the 1.1% JP-10 mixture result shown in Fig. 4.

Experiments performed at an initial temperature above 528 K consistently resulted in autoignition inside the detonation tube during

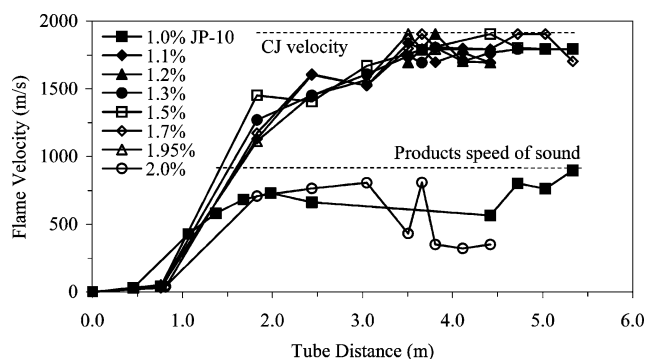


Fig. 3 Flame acceleration of JP-10/air at 373 K and 2 atm.

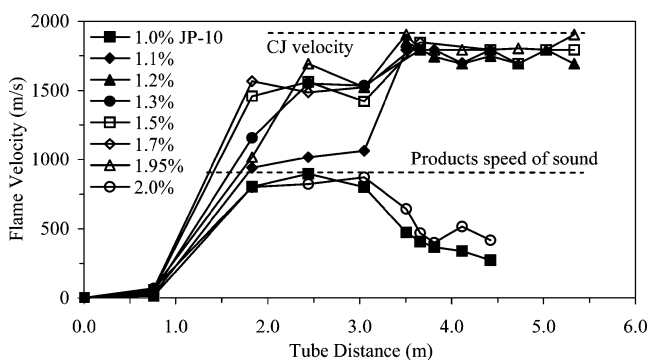


Fig. 4 Flame acceleration of JP-10/air at 473 K and 2 atm.

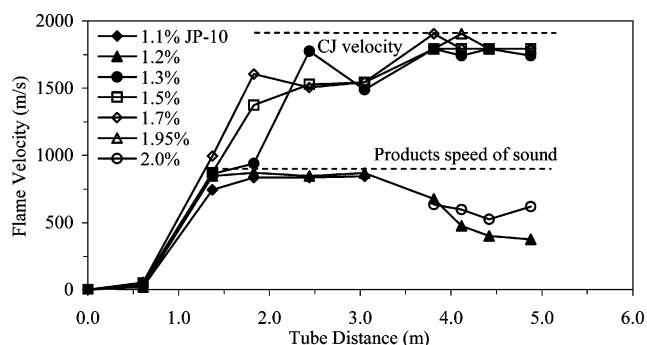
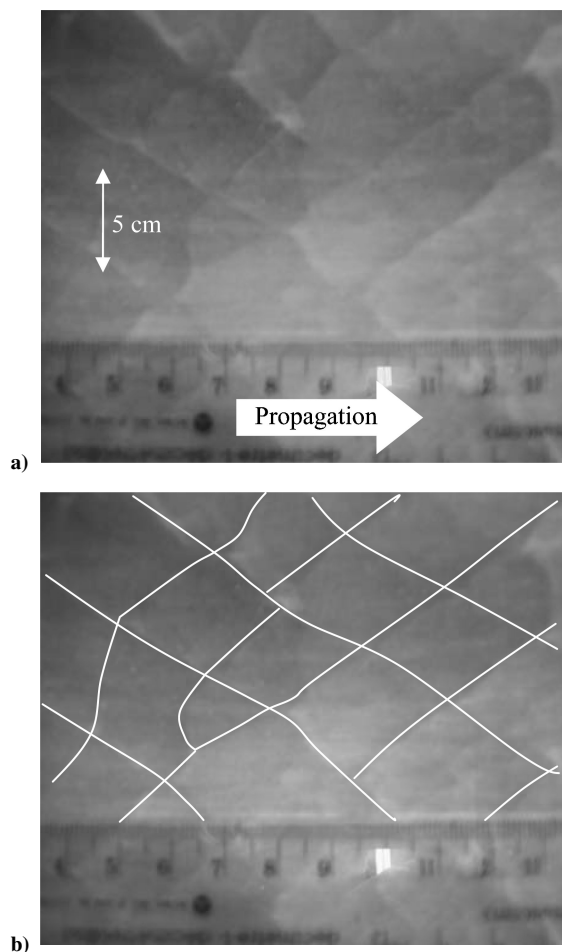


Fig. 5 Flame acceleration in mixtures of JP-10 and air at 528 K and 2 atm.

Table 1 DDT limits of JP-10/air mixtures at 2 atm and different initial temperatures

<i>T</i> , K	Lean limit				Rich limit			
	% JP-10	ϕ	λ , cm	d/λ	% JP-10	ϕ	λ , cm	d/λ
373	1.1	0.75	10.15	0.74	1.95	1.3	8.29	0.9
473	1.2	0.80	6.24	1.20	1.95	1.3	11.58	0.65
528	1.25	0.84	5.28	1.42	1.95	1.3	3.92	1.9

**Fig. 6** Soot foil imprint produced by the passage of detonation wave in a stoichiometric mixture of JP-10 and air at 523 K and 2 atm; dominant triple-point trajectories shown in Fig. 6b.

the fill process. Autoignition ultimately limits the operating temperature of a PDE because ignition is no longer controllable. Based on the flame velocity data presented in Figs. 3–5, the DDT composition limits for the apparatus were identified as a function of the initial mixture temperature. The limits are provided in Table 1. The lean and rich limits define the composition range over which the detonation initiation occurs within the orifice-plate-filled section of the tube. The lean limit is found to gradually increase with increasing initial temperature. For example the lean detonation limit increases from 1.1% JP-10 at 373 K to 1.25% JP-10 at 528 K. A stoichiometric JP-10 air mixture corresponds to 1.5% JP-10. This counterintuitive trend is discussed later in the paper. The rich limit, however, is unchanged at 1.95% JP-10 over the temperature range studied.

B. Cell-Size Measurements

In the tests where detonation initiation occurred, the cell size was measured at the end of the tube where the detonation propagates at a quasi-steady velocity. There was very little substructure in the cellular pattern obtained for stoichiometric mixtures. A photograph of a soot foil obtained for a stoichiometric JP-10 and air mixture at 523 K and 2 atm is provided in Fig. 6a. (Detonation wave propagates from

left to right.) The detonation cellular structure for off-stoichiometric mixtures was found to contain substantial substructure, similar to that observed in hydrogen-air mixtures.¹¹

The detonation cell size can be obtained by either measuring the cell width of individual cells or by measuring the average transverse spacing between parallel triple-point tracks.²⁰ For the track method, which is used exclusively in this study, one can measure the average spacing for all of the triple point tracks, including the substructure, or just the dominant trajectories, which typically appear thicker on the foil (Fig. 6b). Note that the technique using only the dominant trajectories is much more subjective because it requires filtering of the information on the foil. The cell-size data obtained using both techniques for tests performed at 373 K and 2 atm are provided in Fig. 7. The vertical error bars shown for each data point represent the smallest and largest track spacing measured for each foil. If every triple-point trajectory is considered, the average cell size is about 3 cm, and it is fairly constant over the mixture composition range tested. If only the dominant tracks are considered, the average cell size increases for mixtures departing from the stoichiometric composition of 1.5% JP-10. The tube circumference is 31.4 cm, and so there are at least three cells across the foil for all of the measurements made in this study.

A comparison of the cell-size data obtained at 373 K can be made with JP-10 vapor and air data reported by Austin and Shepherd,¹ reproduced in Fig. 8. The Ref. 1 data correspond to a similar initial temperature, that is, 353 K vs 373 K in the present study, but at a lower initial pressure of 1 atm. Note for the Ref. 1 study the cell size was obtained by measuring the cell width of 10 individual cells from the foil, and the error bar represents the smallest and largest cell size measured for the foil. Recall detonation initiation was not observed in the present investigation for a mixture pressure of 1 atm. This suggests that the detonation cell-size decreases with increased initial pressure. However, to within the uncertainty of the measurements, the cell-size measurements are very similar for both studies even though the data correspond to two different initial pressures.

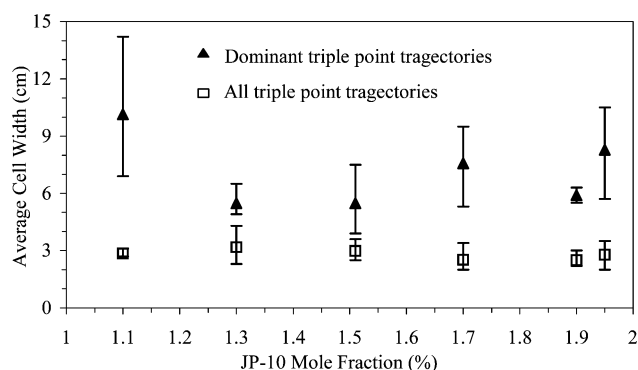
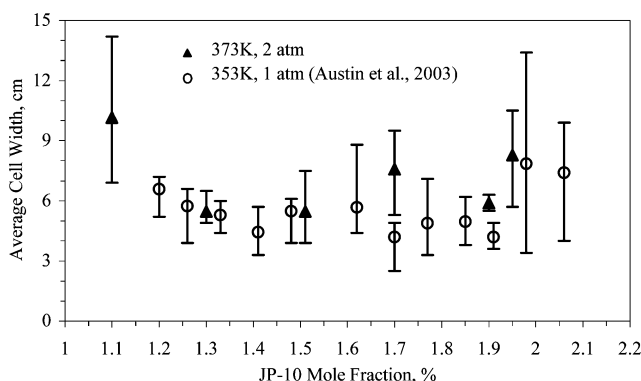
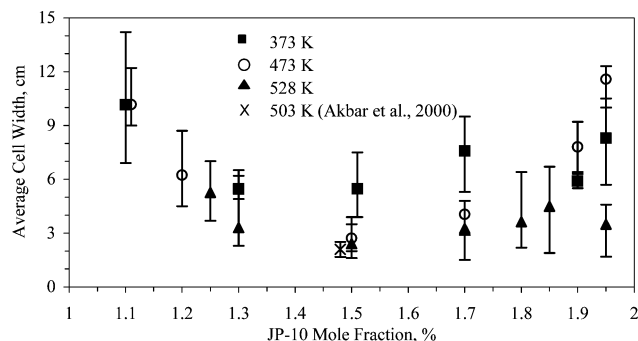
**Fig. 7** Cell-size measurements for JP-10/air at 373 K and 2 atm.**Fig. 8** Comparison of cell-size measurements of JP-10/air at 373 K and 2 atm from the present study (same as Fig. 5 data) and 373 K and 1 atm from Austin and Shepherd.¹

Table 2 Calculated CJ detonation properties for stoichiometric JP-10/Air at 2 atm initial pressure

Initial temperature, K	Shock temperature, K	Shock pressure, atm	Particle velocity, m/s	Induction time, μ s	Induction length Δ , mm	Cell size λ , mm	λ/Δ
373	2041	54.0	362.4	3.7	1.3	54.7	42
473	2141	42.7	377.8	2.8	1.1	27.2	25
528	2200	38.4	386.1	2.3	0.9	24.2	27

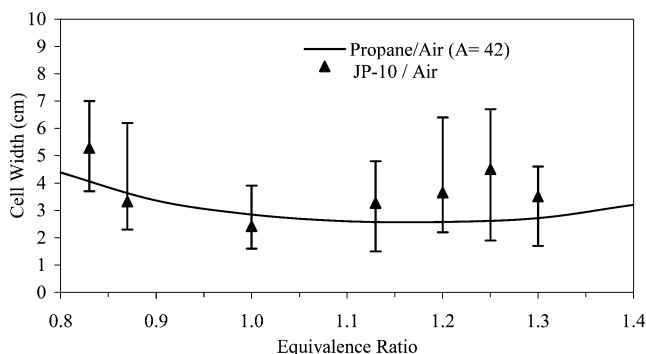
**Fig. 9** Cell-size measurements of JP-10/air at an initial pressure of 2 atm and different initial temperatures.

Additional detonation cell-size measurements were made at 473 and 528 K. The results are presented in Fig. 9 along with the 373 K dominant track data from Fig. 7. Also included in Fig. 9 is a single data point for a stoichiometric mixture reported by Akbar et al.¹² at 503 K and 2.1 atm. This data point is in good agreement with the data obtained at 473 and 528 K, at 2 atm, in the present study. From the results obtained in the present study, it appears that to within the measurement uncertainty there is no marked influence of initial temperature on the detonation cell size. Additional measurements made by Akbar et al.¹² for stoichiometric JP-10 vapor and air at 503 K show a decrease in the average detonation cell size from 3.1 cm at for an initial pressure of 155 kPa to 2.1 cm at 210 kPa with a measurement uncertainty of roughly 1 cm. Again, considering the measurement uncertainty, the Akbar et al. data show little effect of initial pressure on the detonation cell size. This corroborates a similar finding from the comparison of the present data and those obtained by Austin and Shepherd¹ (see Fig. 8).

From the measured detonation cell size one can check if the data can be correlated with the classical DDT limit criterion, that is, $d/\lambda = 1$. Shown in Table 1 is the average cell size measured based on the dominant triple-point trajectories for the DDT limit mixtures. Also provided in the table is the corresponding value of d/λ . The d/λ values vary from a low of 0.65 to a high of 1.9. Taking into account the uncertainty in the cell-size measurements, this shows good agreement with the DDT limit correlation. As pointed out earlier, the lean limit becomes richer with increased initial temperature. As can be seen in Table 1, the lean limit mixture cell size decreases with increased initial temperature. Over this temperature range the value of d/λ increases from 0.74 to 1.42. Keeping aside the uncertainty in the cell-size measurements, one can speculate that the increase in the lean limit is the result of an increase in the detonation cellular structure “regularity” at elevated temperatures. Cell regularity has been shown to affect several detonation phenomenon, including initiation and failure.²¹ However, it is very difficult to quantify cell regularity and its impact on detonation phenomena.

C. JP-10 Cell-Size Correlations

The detonation cell size can be estimated from the calculated ZND induction length. Assuming a linear relationship, $\lambda = A\Delta$, a single data point is required to obtain the constant of proportionality A . The stoichiometric JP-10/air ignition-delay data obtained by Mikolaitis et al.¹⁹ can be used for this purpose. The ignition time is based on the CH signal emitted by the test gas in normal-shock reflection experiments. The following expression for the ignition time as a function of the relected shock pressure and temperature $\tau = BP^n \exp(C/T)$ is proposed by the authors, where based on their

**Fig. 10** Cell-size measurements of JP-10/air and ZND model cell-size prediction for propane/air mixtures at 528 K and 2 atm.

experimental data $n = -0.162$, $C = 14,910$ K. Using the data point obtained at the highest temperature, $T = 1962$ K and $P = 24$ atm yielding $\tau = 4.7 \mu$ s, the constant $B = 4.8 \times 10^{-9}$ s. Using this expression, the ignition times corresponding to the postshock state of the CJ detonation wave for the three initial temperatures tested can be determined. The CJ detonation velocity is calculated at each initial temperature using the chemical equilibrium code STANJAN. Based on the Mach number of the detonation wave, the postshock temperature, pressure, and particle velocity relative to the shock are obtained using normal shock relations. These values are provided in Table 2 along with the calculated ignition time using the Mikolaitis et al. expression. The ZND induction length is calculated by multiplying the measured ignition time by the particle velocity relative to the shock front. The ratio of the measured detonation cell size and the calculated ZND induction length gives the proportionality constant A . It is found that over the temperature range investigated the value of A lies in the range of 25 to 42. This range of values is consistent with the findings from previous studies where detonation cell size was correlated with the ZND induction length for smaller hydrocarbon-air mixtures as well as for hydrogen-air mixtures.^{11,14,15} This finding could be of use for validating future JP-10 reaction mechanisms.

The detonation cell-size measurements for the JP-10/air mixtures are similar in magnitude to that of propane/air mixtures. As a result, it has been suggested that propane can be a useful surrogate fuel for testing purposes.¹ Using the same logic, it might be possible to use the ZND induction length calculated for propane/air, for which reaction mechanisms are readily available, to predict the detonation cell size for JP-10/air mixtures. The ZND detonation induction length for a range of propane/air mixtures at 528 K and 2 atm was calculated using a ZND program developed by Shepherd.¹⁵ The Konnov,¹⁶ reaction mechanism was used for the propane/air calculations. To obtain the proportionality constant A , the detonation cell size was measured for a stoichiometric propane/air mixture at 528 K and 2 atm. Based on the measured cell size of 28.1 mm and the calculated ZND induction length of 0.7 mm, the proportionality constant A is 42. A similar value of A resulted when comparing the measured cell size and the calculated induction length for a stoichiometric JP-10/air mixture using the measured ignition time. Using a value of 42 for the proportionality constant, the detonation cell size for a range of propane/air mixtures was calculated. The results are plotted vs equivalence ratio in Fig. 10 along with the measured detonation cell size for JP-10/air mixtures over a similar equivalence ratio at the same initial pressure and temperature. The agreement in the results from Fig. 10 indicates that propane kinetics can be used satisfactorily to predict the detonation cell size for JP-10/air mixtures.

IV. Conclusions

The experimental data show that the DDT limits are relatively unaffected over the temperature range tested. In fact, the rich DDT limit does not change over the initial temperature range of 373 to 528 K tested. The detonation cell size measured as a function of the JP-10 composition in air was also found to be very insensitive to initial temperature over the test range. Good agreement was obtained between the cell-size data from this study with available JP-10 detonation cell-size data in the literature. The classical DDT limit criterion of $d/\lambda = 1$ is validated if the average cell size is based on the dominant triple-point trajectories, ignoring the cellular substructure. It is shown that the measured JP-10 detonation cell size can be correlated with the calculated ZND detonation induction for a propane/air mixture with the same equivalence ratio. The linear relationship used to scale the induction length data is based on a proportionality constant of 42.

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