A Multiple-Inlet Core for Gas Turbine, Pulse, Pressure-Gain Combustors

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ABSTRACT
Prior tests showed that a maximum increase of stagnation pressure equal to 4% of the compressor absolute delivery pressure was obtained on a very small gas turbine equipped with a prototype, valveless, pulse, pressure-gain, combustor. Accordingly, a new core pulse-combustor has been developed for a proposed pulse, pressure-gain, combustor for larger, more representative, gas turbines. The new core pulse-combustor differs from the earlier prototype design in that the single inlet passage has been replaced with four parallel inlet passages. It is shown that this concept reduces the time required for pre-combustion mixing of the air, fuel and products in the combustion zone. This results in the overall length of the combustor being reduced to about 60% of that required for a single inlet design. It was concluded, on the basis of tests, that a pulse, pressure-gain, combustor incorporating the new core unit should be capable of generating a maximum stagnation pressure-rise of about 10% of the compressor delivery pressure with a volumetric loading 3 to 4 times that of the original prototype.

NOMENCLATURE

C = specific heat at constant pressure
D = combustion zone diameter
L = overall length of combustor
m = mass flow
P = ambient pressure
P = stagnation pressure
T = relevant temperature of mixture (K)
α = oxygen index
γ = ratio of specific heats
ΔP = combustor stagnation-pressure gain (+v) or loss (−v)
η = isentropic efficiency
θ = combustor temperature ratio
τ = ignition delay (ms)
ϕ = cycle temperature ratio

Subscripts
1 = compressor inlet
2 = compressor delivery
C = compressor
T = turbine

Abbreviation
UWP = Uninterrupted-Wetted-Perimeter

INTRODUCTION
Papers have been presented previously (Kentfield and Yerneni, 1987; Kentfield and O'Blenes, 1987; Kentfield and Fernandes, 1990 (a) and (b)) describing the application of a pulse, pressure-gain, combustor, without moving parts, to a very small gas turbine. The pulse-combustor type pressure-gain system served to replace the conventional steady flow combustor normally used on the gas turbine. The purpose of the pressure-gain combustor was to substitute a stagnation pressure rise, between the compressor outlet and turbine inlet, for the stagnation pressure loss associated with the conventional steady-flow combustor. Recent experiments (Kentfield and Fernandes 1990 (a) and (b)) showed that a maximum increase of stagnation pressure equal to 4% of the compressor absolute delivery pressure was obtained on the very small, approximately 0.15 kg/s (0.33 lb/s) mass flow, gas turbine available for the tests. Disadvantages of the system were the adverse influence on the performance of the prototype pressure-gain combustor of the very small mass flow available from the gas turbine and the relatively large bulk of the pressure-gain system compared with that of the conventional steady flow combustor.

Accordingly, a new pulse combustor has been developed, described here, as the core unit for a proposed pulse, pressure-gain, combustor for larger, more representative, gas turbines typically having mass flows, per combustor, in the region of 1.6 kg/s (3.6 lb/s) to 2.4 kg/s (5.2 lb/s) with pressure ratios in the range from 4 to 7:1 respectively. The new core combustor differs from the earlier prototype design in that the single inlet passage has been replaced with
four parallel inlet passages each of half of what would have been the diameter of a single inlet passage had that been used. It is shown that by virtue of an expected reduction of the time required for the pre-combustion physical mixing, in the combustor reaction zone, of the air, fuel and residual products, as a consequence of employing four relatively small diameter inlets, the overall length of the combustor would be reduced substantially compared with that which would have been required for a single inlet design. This should serve, therefore, to reduce the specific bulk, and weight, of a pressure-gain combustor based on the new core design relative to that of the original prototype system.

The original suggestion of employing valveless pulse-combustors as pressure-gain alternatives to conventional steady flow combustors, normally used on gas turbines, appears to be due to Reynst (Thring, 1961). A notable pioneering effort is that of Porter (Porter, 1958) who built, and tested in the laboratory, a valveless, or aerovailed, pulse combustor intended as a model for a subsequent unit suitable for testing on a gas turbine. Fuels used in pulse combustors range from hydrogen to pulverised coal with propane often being found convenient for test work.

In addition to demonstrating a capability for producing a combustion driven pressure gain, pulse combustors are noted for their low NOx emissions due primarily to the very short high temperature residence time, relative to most steady flow combustors, during which fuel and air are in contact. This topic has been studied in more detail by Keller and Hongo (Keller and Hongo, 1988) and by Putnam et al (Putnam et al, 1986). Pulse combustors operating with open exhausts are inherently noisy; however limited operational experience with a pulse, pressure gain, combustor on a gas turbine showed that noise production was not a major problem due, it appears, to the energy extraction occurring in the turbine (Kentfield and O’Blenes, 1987).

PERFORMANCE WITH COMBUSTOR PRESSURE-GAIN

There are a number of ways of presenting the influence of combustor pressure-gain, or loss, on the performances of gas turbines. One direct procedure is to evaluate performance in terms of, for example, cycle efficiency for prescribed combustor generated losses, or gains, of stagnation pressure. Usually such combustor derived losses, or gains, are expressed as percentages of the compressor delivery pressure. A procedure of this type was adopted by Porter (Porter, 1958) who presented, for a prescribed turbine inlet temperature and also compressor inlet temperature, curves of cycle efficiency versus compressor pressure ratio for invariant compressor and turbine efficiencies.

An alternative, but somewhat less precise, form of presentation that also permits the influences of cycle temperature ratios to be included is shown for low pressure-ratio, simple-cycle, gas turbines in Fig. 1. The diagram, which was generated on the basis of an elementary thermodynamic analysis, presents, for combustor pressure gains or losses of small magnitude, the increase in net output, and also it can be shown reduction of specific fuel consumption, resulting from a one percent reduction of combustor pressure loss, or a one percent increase of pressure gain. The selection of a low compressor isentropic efficiency of only 0.7 was based on the likelihood of the use of a simple single-stage centrifugal compressor for cycles having pressure ratios of 5:1 or less. As can be seen from the diagram the relative performance benefits of combustor pressure gain are greatest for low temperature ratio, very low pressure ratio, cycles.

Another procedure for presenting the benefits of combustor stagnation pressure gain, or reduction of pressure loss, is to evaluate the equivalent increase required in the efficiency of a specified engine component (or components) to yield a performance, using a conventional steady flow combustor incurring a pressure loss, equal to that obtainable with the improved component (or components) in conjunction with a pressure-gain combustor. Figure 2 is an example of this type: it shows the improvement in compressor isentropic efficiency needed to achieve a performance equal to that corresponding to the indicated value of the parameter $\Delta P/P_2$. The baseline, or unimproved, condition applicable to Fig. 2 was $\eta_C = 0.80$; it was also assumed that for the steady flow combustor $\Delta P/P_2 = -0.05$. 

![Figure 1: Influence of Combustor Pressure-Gain on the Performance of Low Pressure-Ratio, Simple-Cycle, Shaft Power Gas Turbines.](image1.png)

![Figure 2: Required Increase of $\eta_C$ Above a Base Value of $\eta_C = 0.80$, Versus Compressor Pressure Ratio, to Yield the Same Performance As That Obtainable With $\eta_C = 0.80$ For the Indicated Value of $\Delta P/P_2$.](image2.png)
mixing process. It is hypothesised that, to a first approximation, a typical mixing path for full mixing of pulse, pressure-gain, combustor is the length of the tailpipe and the inlet. The inertia of the outflowing gas column in the tailpipe is sufficient to stop, and subsequently reverse, the inlet backflow with the result that a new air charge is drawn into the combustion zone. The inflowing air stream is then mixed with fuel, supplied under pressure, entering the combustion zone via suitable fuel jets. Re-ignition then occurs spontaneously due to the presence of residual products of combustion remaining within the combustion zone.

In a gas turbine application the air flow to the combustor comes from the engine compressor via the air-inlet plenum. The products of combustion are directed into the engine turbine, as indicated in Fig. 3, at a higher stagnation pressure than that of the compressor delivery airflow. The core pulse-combustor is ignited by suitable fuel jets. Re-ignition then occurs spontaneously due to the presence of residual products of combustion remaining within the combustion zone.

**FIG. 3** CONFIGURATION OF EARLIER PROTOTYPE VALVELESS, PULSE, PRESSURE-GAIN, COMBUSTOR FEATURING A SINGLE-INLET CORE UNIT (DIAGRAMMATIC)

**Prototype Configuration**

The configuration of the prototype pulse, pressure-gain, combustor developed earlier is illustrated diagrammatically in Fig. 3. The development of this unit, which has been described previously (Kentfield and Fernandes, 1990(a), was in large part an experimental activity based on the formulation of a proven design of pulse combustor of the SNECMA-Lockwood type (Lockwood, 1962). The pulse combustor, which was propane fuelled, can be seen on the center-line of the apparatus. The pulse combustor fires intermittently at a frequency, dependent primarily upon the flow path length, in the region of 200 Hz. The combustion reaction leads to a transient pressure rise within the combustion zone with a resultant outflow of combustion products into both the tailpipe and the inlet. The inertia of the outflowing gas column in the tailpipe is sufficient to stop, and subsequently reverse, the inlet backflow with the result that a new air charge is drawn into the combustion zone. The inflowing air stream is then mixed with fuel, supplied under pressure, entering the combustion zone via suitable fuel jets. Re-ignition then occurs spontaneously due to the presence of residual products of combustion remaining within the combustion zone.

In a gas turbine application the air flow to the combustor comes from the engine compressor via the air-inlet plenum. The products of combustion are directed into the engine turbine, as indicated in Fig. 3, at a higher stagnation pressure than that of the compressor discharge flow. The core pulse-combustor is subjected to forced convection cooling due to a portion of the compressor delivery airflow being pumped over the exterior of the device by means of the pulse-combustor-inlet backflow. It is apparent from Fig. 3 that a major factor governing the length of the pulse, pressure-gain, combustor is the length of the core pulse combustor itself.

**Advantages of Multiple Inlets**

The inherent advantages of employing multiple, relatively small diameter, inlet passages in place of a single, relatively larger diameter, inlet having a flow area equal to the sum of the flow areas of the multiple inlets stems from the expectation of a more rapid mixing process. It is hypothesised that, to a first approximation, a typical mixing path for full mixing of the entering air and fuel flows with each other, and with the residual products residing in the combustion zone, will be directly proportional to the diameter of each inlet passage. Thus for conditions typical of those applicable during the induction process of a highly loaded single-inlet pulse combustor physical mixing can be expected to occupy about 20 to 25% of the duration of the pulse-combustor operating cycle (Olorunmaiye and Kentfield, 1989).

Partly in addition to, and partly concurrent with, the physical mixing process is the duration of the chemical kinetic processes or ignition delay. This is normally computed, for steady flow systems, on the basis of the mixed temperature of the reactants. For a pulse combustor it would appear that a more relevant temperature would be a temperature between the fully mixed temperature of the air, fuel and residual products and the temperature of the residual products themselves. The mixing process could well result in local well mixed regions occurring relatively early during the induction process in which relatively small pockets, or portions, of the entering flow become well mixed with relatively large portions of residual products and hence transiently, before completion of mixing as a whole, attain temperatures greater than the true, bulk, mass-averaged mixed temperature. The sensitivity of the duration of the ignition delay to the relevant temperature in the activation energy based, kinetic, ignition delay equation recommended by Miller (Miller, 1959) is apparent:

\[
\tau = \frac{4.88 \times 10^{-13}}{\alpha} \left(\frac{32,400}{T}\right) e^{1.02} \text{ ms}
\]

Where:

- \(\tau\) = delay period (ms)
- \(\alpha\) = oxygen index (= 0.21 for air)
- \(T\) = relevant mixture temperature (K)

The Miller formulation, specifically for Calor gas a fuel fairly similar to propane, applied to conditions representative of highly loaded pulse combustors suggests that, to a first approximation:

\[0.05 \text{ ms} \leq \tau \leq 0.3 \text{ ms}\]

Hence the ignition delay lies within the range, for a pulse combustor operating at about 200 Hz, from about 1 to 6% of the cycle duration and hence is very much less than the time required for physical mixing. Since ignition delay is essentially independent of the duration of the mixing process it can be expected that, for example, the substitution of four inlets for a single inlet will essentially halve the duration of physical mixing but will have little or no influence on ignition delay. Consequently it can be expected that an optimised four-inlet combustor of prescribed combustion zone diameter will be greater than half of the length of an optimised single inlet version. Alternatively, the use of four inlets should allow an optimised configuration to be built of only slightly greater length than an optimised single inlet unit of half the diameter. The latter consideration was the basis for the work reported here.

Another factor of relevance relating to the use of multiple inlets is that what has been termed the Uninterrupted-Wetted-Perimeter (UWP). This parameter quantifies the sum of the free wetted perimeters of the inlet-air flow normalised by the perimeter of a single air inlet having a flow cross-sectional area equal to
that of the sum of the multiple inlets. The UWP parameter can be evaluated at any desired elapsed fraction of the induction portion of the pulse-combustor cycle. Since the inlet air flows entering the combustion zone of a valveless pulse combustor have been shown, by flow visualisation, to develop mushroom-like recirculating heads the maximum diameter of each jet increases rapidly as it penetrates further into the combustion zone (Rehman, 1976). The jet diameters increase until they interfere, mutually and/or contact the wall of the combustion zone. This interference limits the free, or uninterrupted, diameters of the jets available to continue to entrain residual products of combustion residing within the combustion zone.

The UWP concept is illustrated in Fig. 4 which shows, diagrammatically, an end view of a multiple (i.e., four) inlet pulse-combustor combustion zone. The underlying assumption is, therefore, that the mixing effectiveness of the inlet flows can be expected, to a first approximation, to be proportional to the UWP value. Figure 5 shows the UWP values at the beginning and end of the induction process versus the number of discrete, circular cross-section, inlets. A mean curve has also been added to Fig. 5. In each case the effective divergance angle of the inflowing jets has been assumed to be equal to that of a single central jet as established by means of flow visualisation. It can be seen from Fig. 5 that whilst, at the beginning of induction four inlets have twice the UWP value of a single, central, inlet the mean UWP over the duration of induction is only about 20% greater than the mean value for a single inlet. It would appear from Fig. 5 that six inlets would be a much better choice than four. However, this increases the complexity of the system and also the inherent intake friction losses since the smaller the inlet duct diameter the greater the (tuned) inlet length-to-diameter ratio. The need to maintain optimum inlet, and tailpipe, lengths is paramount since the entire pulse combustor constitutes a tuned system. This consideration renders it impractical to substitute, say, six short inlet passages, to improve mixing, for four inlets of optimum (tuned) length.

### Optimisation of the Four-Inlet Core Combustor

Although prediction, by means of the method-of-characteristics, of the performance of highly loaded pulse combustors is fairly well advanced (Olorunmaiye and Kentfield, 1989) shortcomings remain in predicting the performance of combustors of prescribed geometry with sufficient accuracy to perform, by repeated computations for different geometries, an optimisation of the configuration of such devices by purely theoretical means. One of the sources of difficulty is the need to make major assumptions relating to the pre-combustion mixing process and also the combustion process itself.

Accordingly, a prototype four-inlet, propane fuelled, core combustor was designed and constructed, as shown in Fig. 6, in order to perform an experimentally based optimisation. The combustor was fabricated in such a manner that it was possible to vary, independently, the lengths of the inlets, combustion zone and tailpipe. Provision was also made to vary the number, and flow cross-sectional area, of the multiple fuel jets set around the perimeter of each inlet. The cross-sectional areas selected for the inlets and for the tailpipe throat and exit as fractions of the combustion zone cross-sectional area were the same as the corresponding ratios for the well proven single-inlet SNECMA-Lockwood valveless pulse-combustor configuration (Lockwood, 1962) constituting the core unit of the prototype pulse, pressure-gain, combustor illustrated in Fig. 3.

### Performance of the Four-Inlet Combustor

The four-inlet combustor was tested, with ambient
intake conditions, as if it were a static thrust-producer, i.e. a static pulsejet. It has been shown previously (Kentfield and Fernandes, 1990(a)) that the pressure gain \( \Delta P/P_{\text{AMB}} \) expected from the combustor is, to a first approximation, directly proportional to the square of the inverse of the specific fuel consumption of the unit operating as a thrust generator or pulsejet. The thrust measurements were made by means of two, suspended, heavy thrust plates, one mounted near the air inlets the other near the tailpipe exit. Each plate was arranged with one surface normal to an efflux of the pulse combustor. The deflection from the equilibrium position of the inlet-end thrust plate recorded the thrust generated by the inlet backflow, the other plate recorded the thrust generated by the tailpipe outflow. Checks were made to ensure that the flow deflected by each plate had, in fact, been turned through a right angle. Thrust plate methods are relatively commonly used procedures for making thrust measurements of pulsejets (Lockwood, 1962). The thrust of interest was the arithmetic sum of the forward and rearward directed thrusts due to the inlets and tailpipe respectively. In a complete pulse, pressure-gain, combustor flow rectifiers are employed to redirect rearwards the inlet backflow. The ejector connected to return bends constitutes the single flow-rectifier of the system illustrated in Fig. 3.

Whilst full details of the experimental optimisation test procedures, equipment, and results are available (Speirs, 1989) only major findings are summarised here. It was found, comparatively early in the program, that the performance was generally substantially better when twenty four fuel jets were employed rather than half that number. Figure 7 illustrates a typical comparison, on the fuel consumption versus thrust plane, of performances obtained with twenty four and only twelve fuel injection nozzles. The total of the fuel-nozzle exit areas were equal, at an optimum value, for both cases. Figure 8 shows, on the fuel consumption versus thrust plane, the thrusts produced by the inlet backflow and tailpipe and exit flow, in addition to the arithmetic sum of these, for the optimised combustor configuration which had a length-to-diameter ratio \((L/D)\) of 10.01.

The pressure amplitudes recorded in the combustion zone of the optimised configuration are presented, as functions of time, in Fig. 9 for a fuel-flow rate of approximately half the maximum value and in Fig. 10 for a fuel-flow rate very close to the maximum achievable. It should be noted that the ambient pressure at the Calgary test site is approximately 88% of that at sea level due to the influence of altitude. Hence, approximately 14% greater fuel flow rates, pressure amplitudes and thrust values can be expected for sea-level operation.

COMPARISON WITH SINGLE-INLET PERFORMANCE

Figure 11 shows a comparison, on the specific thrust versus specific fuel consumption plane, of the thrust generating performances of the single inlet core combustor of the original prototype pulse, pressure-gain, combustor of Fig. 3 with the performance of the optimised four-inlet core pulse-combustor. On the basis of the previously referred to approximate relationship connecting the square of the inverse of specific fuel consumption with pressure-gain potential (Kentfield and Fernandes, 1990(a)) the potential pressure gain of the four-inlet combustor is, due to a lower specific fuel consumption, between 2 and 3.5 times that of the single inlet prototype combustor. The lower value is applicable at low specific thrusts, the higher value is applicable approaching maximum specific thrust. Since the original prototype pulse, pressure-gain, combustor (Fig. 3) has been shown to produce, operating on a small gas turbine, a maximum stagnation pressure-gain of 24% and a minimum stagnation pressure-gain of approximately 1.3% (Kentfield and Fernandes, 1990(a)) the corresponding, most optimistic, pressure-gain expectation would lie in the range from a minimum of about 2.6% to a maximum of about 14% for a
FIG. 8 DIVISION OF THRUST GENERATION BETWEEN THE TAILPIPE OUTFLOW AND THE INLET BACKFLOW. THE DOTTED CURVE IS THE ARITHMETIC SUM OF THE THRUST COMPONENTS. OPTIMISED FOUR-INLET CONFIGURATION

FIG. 9 PRESSURE-TIME DIAGRAMS RECORDED IN THE COMBUSTION ZONE OF THE OPTIMISED FOUR-INLET CONFIGURATION AT APPROXIMATELY HALF OF THE MAXIMUM FUEL-FLOW RATE (20.2 kg/h; AMBIENT PRESSURE = 89 kpa)

FIG. 10 PRESSURE-TIME DIAGRAMS RECORDED IN THE COMBUSTION ZONE OF THE OPTIMISED FOUR-INLET CONFIGURATION AT APPROXIMATELY THE MAXIMUM FUEL-FLOW RATE (39.3 kg/h; AMBIENT PRESSURE = 89 kpa)

pulse, pressure-gain, combustor based on the new, larger, four-inlet core unit. Since the 4% pressure gain achieved experimentally with the prototype unit (Fig. 3) was obtained using an extremely low pressure ratio gas turbine it can be expected that for more representative, higher pressure ratio, gas turbines the pressure gain achievable will be reduced because, for a prescribed maximum turbine inlet temperature, the combustor temperature ratio will be lower. When an allowance is made for this influence a reasonable expectation for the pressure gain of a pressure-gain combustor based on the four-inlet core is in the region of 10% or, more conservatively, 7% for a relatively compact installation with higher internal losses than those applicable to the bulky arrangement of the prototype unit (Fig. 3).

The lower specific fuel consumption of the four-inlet core combustor is not due solely to the use of four inlets but is also due to the larger flow cross-sectional areas incorporated. The combustion zone internal diameter of the single inlet combustor, the performance of which is shown dotted in Fig. 11, was 61 mm (2.4 in) whereas that of the four-inlet unit was 152 mm (6 in.). It has been shown previously (Kentfield, Rehman and Cronje, 1980) that the performance of pulse combustors is reduced dramatically, for geometrically similar units, when the diameter is made very small. The length-to-diameter ratio, L/D, of the single inlet unit was 16.77 whilst that of the four-inlet combustor was 10.01. These ratios imply that an optimised four-inlet combustor of twice the diameter of an optimised single-inlet combustor is just under 20% greater in length rather than being of equal length which might have been expected on the basis of the most simplistic mixing concept and with neglect of chemical-kinetic considerations.

In fact a four-inlet combustor having a length essentially equal to that of an optimised single-inlet unit of half the diameter can be made to operate although with a degraded performance relative to that of an optimised four-inlet configuration. Such a comparison is presented in Fig. 12. The dotted curve represents the performance of a single inlet combustor of 73 mm (2.875 in) combustion zone diameter, L/D =
16.77, whilst the other curve is for a four inlet combustor of 152 mm (6 in) combustion zone diameter for which L/D = 8.60 having, therefore, an overall length approximately equal to that of a single-inlet unit of half the diameter. It can be seen, by comparing the curves of Fig. 11 and 12 for the four-inlet combustors, that both the specific fuel consumption, and maximum specific thrust are poorer for the shortened unit of Fig. 12. Comparison of the dotted curves of Fig. 11 and 12 for the geometrically similar, optimised, single-inlet units serves to emphasise the point made previously in connection with the relationship noted between the size (e.g. combustion zone diameter) and the performance of geometrically similar pulse combustors.

**VOLUMETRIC LOADING**

An advantage of the relative shortness of a multiple-inlet core pulse-combustor is the beneficial influence of this feature in terms of the volumetric loading, and specific weight, of the complete pulse, pressure-gain, combustor. Additionally it would appear, in the light of recent operating experience, that the design of the air-inlet plenum chamber constituting a portion of the original pulse, pressure-gain, combustor (Fig. 3) was particularly conservative and, consequently, it should be possible to increase the loading of a pulse, pressure-gain, combustor incorporating the new four-inlet core unit by a factor of 3 or 4 relative to that of the original prototype. However even this improvement is insufficient to be likely to increase the volumetric loading of a pulse, pressure-gain, combustor to greater than, at best, about half that of a typical steady flow combustor.

The inherent reason for the relatively low volumetric loading of pulse, pressure-gain, combustors is the volume occupied by the essential tuned passages etc., a requirement absent from the design of conventional steady flow combustors. The low (overall) loading feature is particularly ironic when it is noted that based on combustion-zone volume only, the sea-level rating of the four-inlet combustor described here is 194 MW/m² atm. (18.8 x 10⁸ Btu/ft² h atm.).
CONCLUSIONS

A four-inlet core pulse-combustor intended for incorporation in a pulse, pressure-gain, combustor for small gas turbines having mass flows in the range from about 1.6 kg/s (3.6 lb/s) to 2.4 kg/s (5.2 lb/s) operating at pressure ratios from about 4 to 7:1 has been fabricated and subjected to testing at ambient conditions. On the basis of the demonstrated pressure-gain performance, on a very low pressure ratio gas turbine, of an earlier, smaller, unit featuring a single-inlet core pulse combustor, the minimum and maximum pressure-gains expected are 2.6% and 14%, respectively, of the compressor absolute delivery pressure.

In view of the influence of cycle pressure ratio on combustor temperature ratio, and hence combustor pressure gains, conditions imply, for the proposed applications, maximum expected pressure gains in the range from about 7 to 10% of the compressor delivery pressure. It was also found that a pulse, pressure-gain combustor incorporating a four-inlet core unit is expected to achieve an overall volumetric loading about 3 to 4 times greater than that of the earlier, demonstrated, prototype, pulse, pressure-gain, combustor.

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