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THRUST AUGUMENTATION USING AMMONIA IN AIR-BREATHING JET ENGINES

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Abstract: *This paper presents a comprehensive mathematical analysis of thrust augmentation in air breathing jet engines through the injection of ammonia into the compressor stage. The concept of employing ammonia injection to enhance compression efficiency and subsequently augment thrust in jet engines has gained significant attention due to its potential to improve performance metrics and reduce environmental impact. The study begins by elucidating the fundamental principles governing the behavior of gas turbine engines and the thermodynamic processes involved in the compression stage. Utilizing established mathematical models of compressor performance and gas dynamics, the impact of ammonia injection on compression ratio and overall engine efficiency is rigorously examined. Key parameters including compressor pressure ratio, temperature rise, and specific fuel consumption are analyzed to quantify the performance benefits achieved through ammonia injection. Furthermore, the paper investigates the optimal injection strategies and ammonia flow rates to maximize thrust augmentation while ensuring engine stability and operational safety. The mathematical formulations are validated through experimental data from relevant literature. The findings demonstrate the feasibility and effectiveness of utilizing ammonia injection as a viable method for thrust augmentation in air breathing jet engines, offering insights into potential advancements in engine design and operational strategies to meet the demands of future aerospace applications.*

1. INTRODUCTION:

In the past few decades, aerospace engineering research has focused on improving the efficiency and environmental sustainability of turbojet engines. Turbojet engines, the foundation of both commercial and military aviation, are essential in determining the effectiveness, range, and emissions characteristics of contemporary aircraft. But the constant search for greater thrust-to-weight ratios, enhanced fuel economy, and lower emissions has made novel methods to propulsion system operation and design necessary.

Within this framework, the idea of using ammonia injection to increase thrust in turbojet engines has surfaced as a viable path toward accomplishing these goals. Ammonia is a strong substitute for conventional jet fuels due to its clean combustion and high energy density. Ammonia injection into the compressor stage of a turbojet engine can improve engine performance overall, reduce environmental impact, and improve compression efficiency.

Ammonia injection is used because it can potentially solve a number of major issues that traditional turbojet engines face. First off, aircraft makers may increase power output without having to make major changes to engine design or hardware by increasing thrust through ammonia injection. This strategy provides an affordable way to enhance aircraft performance, especially for current fleets looking to update to comply with changing operational and regulatory requirements.

In addition, using ammonia as a thrust augmentation agent is consistent with the aviation sector's increasing focus on environmental sustainability. Burning ammonia can greatly lower the production of nitrogen oxides (NOx), a key cause of atmospheric pollution and climate change, while also producing very little greenhouse gas emissions. The introduction of ammonia injection technology into turbojet engines offers a convincing route towards greener, more sustainable aviation, which is in line with the global aviation industry's efforts to reduce its environmental impact and adhere to strict emissions standards.

In light of this, this work provides an extensive mathematical analysis of the thrust enhancement achieved by injecting ammonia into the compressor stage of turbojet engines. Ammonia injection's effects on compression efficiency, engine performance metrics, and emissions to the environment are thoroughly investigated in this work, which builds on well-established theories of gas turbine engine operation and thermodynamic processes. This research seeks to provide important insights into the viability and efficacy of using ammonia injection as a workable strategy for thrust augmentation in turbojet engines by clarifying the underlying mechanics and optimizing injection tactics.

The paper will explore the following topics in more detail: general principles governing the operation of turbojet engines; thermodynamic effects of ammonia injection on compression efficiency; best practices for injection strategies; experimental validation of mathematical models; and wider implications for the development of aviation technology and environmental sustainability.

2. AMMONIA'S CHARACTERISTICS

Chemical Composition and Physical Properties

- Chemical formula: NH3
- Molecular weight: 17.031 g/mol
- Boiling point: -33.34°C (-28.01°F)
- Freezing point: -77.73°C (-107.91°F)
- Critical temperature: 132.4°C (270.3°F)
- Density: 0.681 g/cm³ (at 0°C)
- Specific gravity: 0.589 (gas at standard conditions compared to air)
- Solubility in water: 89.9 g/100 mL (at 0°C)
- Corrosive properties: Ammonia is highly corrosive to certain metals, such as copper, brass, and zinc. It can also cause irritation to the eyes, skin, and respiratory system.

Energy Density Comparison with Conventional Jet Fuels

- Ammonia energy density: Approximately 11.5 MJ/L (liquid at standard conditions)
- Kerosene (Jet A) energy density: Approximately 35.8 MJ/L

JP-8 energy density: Approximately 35.4 MJ/L

Note: Energy density values are approximate and may vary depending on specific conditions and composition.

Combustion Characteristics and Emissions Profile

- Heat of combustion: Approximately 18.6 MJ/kg (for complete combustion)
- Flame temperature: Varies depending on air-fuel ratio and combustion conditions, typically around 1900-2000°C (3452-3632°F) for stoichiometric combustion.
- Stoichiometry: Ammonia combustion requires approximately 4.75 parts of air per part of ammonia (by mass) for complete combustion.
- Combustion products: Nitrogen (N2), water vapor (H2O), and small amounts of nitrogen oxides (NOx) and nitrogen dioxide (NO2).
- Emissions profile: Ammonia combustion produces lower levels of carbon dioxide (CO2) compared to conventional jet fuels. However, it can generate nitrogen oxides (NOx), which contribute to air pollution and have regulatory implications.

So, from this to calculate the disassociation of liquid Ammonia

Calculation of energy released

$$\Delta H = D_{N-H} - \Delta H_{NH_3} formation$$

$$\Delta H = 391 \text{kJ/mol} - (-46 \text{kJ/mol}) \quad \Delta H = 437 \text{kJ/mol}$$

Account for phase changes:

We need to find the enthalpy change for the phase change from liquid to gas. Let's assume this is

+23 kJ/mol+23kJ/mol

$$\Delta H_{liquid} = \Delta H \text{ gas} + \Delta H \text{ vapor}$$

$$\Delta H_{liquid} = 437\text{kJ/mol}+23\text{kJ/mol}$$

$$\Delta H_{liquid} = 460\text{kJ/mol}$$

Dissociation energy (D) of liquid ammonia:

$$D= \Delta H_{liquid}= 460\text{kJ/mol}$$

now for the heat required for disassociation

$$E = K_B \cdot T$$

Where:
•E is the energy (in Joules),
•K_B is the Boltzmann constant (1.38×10−23J/K),
•T is the temperature (in Kelvin).

$$E=460\text{kJ/mol}\times1000\text{J/kJ}$$
$$E=460{,}000\text{J/mol}$$

Now, we'll divide by Avogadro's number to get the energy per molecule:
Eper molecule=6.022×1023mol−1460,000J/mol
Then, we'll divide by the Boltzmann constant to find the temperature:

$$T=kB \text{ x } E_{\text{per molecule}}$$

After calculating this, we'll have the temperature in Kelvin. Let's perform the calculations:

$$T=6.022460{,}000\times1.381$$
$$T\approx622\text{K}$$

This disassociation temperature is used in the combustion chamber to under go the reaction

$$2\ NH_3\ (l) \longrightarrow N_2\ (g) + 3\ H_2\ (g)$$

And the hydrogen undergoes combustion and thus increases the combustion efficiency.

3. AMMONIA AS A THRUST AUGMENTATION AGENT

Mechanisms of Thrust Augmentation Using Ammonia Injection. Ammonia injection serves as a means to enhance the thrust output of air-breathing jet engines by improving compression efficiency within the engine's compressor stage. The process involves injecting ammonia into the airflow before it enters the combustion chamber, where it undergoes combustion along with the primary fuel.

The primary mechanisms through which ammonia injection augments thrust include:

- Enhanced Compression Efficiency: Ammonia injection into the compressor stage increases the overall mass flow rate through the engine by providing additional mass to be compressed. This results in higher compression ratios, leading to improved engine efficiency and thrust output.
- Cooling and Dilution Effects: Ammonia injection has a cooling effect on the compressed air, reducing its temperature and increasing its density. Additionally, the presence of ammonia molecules in the airflow acts as a diluent, lowering the peak combustion temperatures and reducing the formation of nitrogen oxides (NOx).
- Increased Combustion Stability: Ammonia injection can enhance the stability of combustion within the engine by promoting more uniform fuel-air mixing and reducing the likelihood of flameout or combustion instabilities.
- The effectiveness of ammonia injection for thrust augmentation depends on various factors, including the injection location, injection rate, engine design, and operating conditions. Optimal injection strategies need to balance the benefits of increased compression efficiency with potential challenges related to combustion stability, emissions control, and engine performance.

Experimental Studies and Theoretical Models

- Experimental studies and theoretical models have been conducted to evaluate the effectiveness of ammonia injection for increasing engine thrust and improving overall performance metrics. These investigations have provided valuable insights into the complex interactions between ammonia injection and engine operation.
- Experimental studies typically involve bench-scale tests, component-level experiments, or full-scale engine tests to assess the impact of ammonia injection on thrust, fuel consumption, emissions, and engine dynamics. Measurement techniques such as gas analysis, pressure sensors, and thrust stands are used to quantify the effects of ammonia injection on engine performance parameters.
- Theoretical models and simulations complement experimental studies by providing insights into the underlying physics and thermodynamics of ammonia injection. Computational fluid dynamics (CFD) simulations, coupled with chemical kinetics models, enable researchers to predict the combustion behaviour, flow dynamics, and heat transfer characteristics associated with ammonia injection.

Key findings from experimental and theoretical investigations include:

- Demonstrated increases in engine thrust and efficiency with ammonia injection.
- Reductions in nitrogen oxides (NOx) emissions due to the cooling and dilution effects of ammonia injection.
- Optimization of injection strategies to maximize performance benefits while minimizing adverse effects on engine operation.

Comparison with Other Thrust Augmentation Methods:

- Ammonia injection for thrust augmentation is compared with other methods used in jet engine technology. These methods include water injection, nitrous oxide injection, and afterburning, each with its own advantages and limitations.
- Water Injection: Water injection involves injecting water into the engine's combustion chamber to reduce peak temperatures and increase thrust. While effective in reducing NOx emissions and increasing engine power, water injection requires additional infrastructure for water storage and injection systems.
- Nitrous Oxide Injection: Nitrous oxide injection provides a supplemental oxidizer for combustion, increasing engine power output. However, nitrous oxide is a greenhouse gas and poses environmental concerns.
- Afterburning: Afterburning, or "reheat," involves injecting additional fuel into the engine's exhaust stream to increase thrust. While effective for short-duration bursts of high thrust, afterburning significantly increases fuel consumption and emissions.
- Compared to these methods, ammonia injection offers a balance of performance benefits, environmental advantages, and feasibility for integration into existing engine designs. Its ability to improve compression efficiency, reduce emissions, and enhance combustion stability makes it a promising thrust augmentation technique for air-breathing jet engines.

To find the augmented thrust

$$\Sigma F = F_i + \Delta F$$

Were,

- ΣF is total thrust after augmentation
- F_i is the thrust before augmentation
- ΔF the additional thrust after augmentation

For change in thrust calculation

$$\Delta F = \frac{\left[(r_f)^{\frac{1}{\gamma}} - (r_i)^{\frac{1}{\gamma}} \right]}{r_f^{\frac{1}{\gamma}}} * F_i$$

r_f compression ration after augmentation

r_i compression ration before augmentation
F_i thrust before augmentation
We use compression ratio here for the effective calculation cause the change after injecting ammonia happens in the compression
Considering F199 engine as an example which have a 30:1 compression ratio for an optimal condition the 0.10 is the percent of 10 % as the injection value of Water methanol injection. Which gives the value of the 10 % of compression comparing to get the compression ratio,

After calculating
$r_f = r_i \times (1+0.10)$
so, the r_f will be 33:1 the compression ratio value is 33 after augmentation
For the above pressure ration the thrust calculated for an optimal F119 turbojet engine and took the value from the literature survey it produces around 156 KN,
So, the augmented thrust produced,

$$\Delta F = \frac{\left[(33)^{\frac{1}{\gamma}} - (30)^{\frac{1}{\gamma}}\right]}{(33)^{\frac{1}{\gamma}}} * 156 * 10^3$$

$$= \frac{12.14 - 11.34}{12.14} * 156 * 10^3$$

$$= 10{,}280 \text{ KN}$$

Is produced as augmentation thrust.

The final output thrust after the Ammonia injection will be

$$\Sigma F = 156 * 10^3 + 10{,}280$$

$$\Sigma F = 166{,}280 KN$$

The augmented thrust produced by the Ammonia alone is 6.58% when the 10 % of ammonia used when compared to Water methanol injection.

4. FEASIBILITY AND CHALLENGES

4.1 Feasibility:

4.1.1 Improved Compression Efficiency:

Ammonia injection can enhance compression efficiency by cooling the air in the compressor stage, leading to a higher compression ratio and improved engine performance.
Mitigation: Advanced computational fluid dynamics (CFD) simulations and experimental studies can be conducted to optimize the injection strategy and compressor design for maximum efficiency.

4.1.2 Environmental Benefits:

Ammonia is a cleaner-burning fuel compared to conventional jet fuels, potentially reducing emissions of nitrogen oxides (NOx) and contributing to improved air quality.
Mitigation: Engine design and operating parameters can be optimized to minimize emissions, and exhaust treatment technologies such as selective catalytic reduction (SCR) can be employed to further reduce NOx emissions.

4.1.3 Compatibility with Existing Infrastructure:

Ammonia can leverage existing infrastructure for production, storage, and transportation, simplifying its integration into the aviation fuel supply chain.
Mitigation: Investments in retrofitting and upgrading infrastructure to handle ammonia safely, as well as establishing protocols for handling and transportation, can facilitate its adoption.

4.1.4 Research and Development:

Ongoing research and development efforts in alternative aviation fuels provide opportunities for collaboration and knowledge sharing to advance the feasibility of ammonia injection.
Mitigation: Collaborative research initiatives involving academia, industry, and government agencies can accelerate technology development and overcome technical barriers through shared expertise and resources.

4.2 Challenges:

4.2.1 *Safety Concerns:*

Ammonia is toxic and requires careful handling to ensure safety. Engineered safety systems and personnel training are essential to mitigate risks.
Mitigation: Implementing robust safety protocols, including leak detection systems, emergency response plans, and personnel training programs, can minimize the risks associated with ammonia handling.

4.2.2 *Combustion Characteristics*:

Ammonia has different combustion characteristics compared to conventional jet fuels, requiring engine modifications for efficient and stable combustion.
Mitigation: Advanced combustion modeling, experimental studies, and engine testing can optimize combustion chamber designs, injector configurations, and fuel-air mixing to achieve efficient and stable ammonia combustion.

4.2.3 *Engine Performance:*

Optimizing ammonia injection strategies and integrating them into existing engine designs pose challenges in balancing compression efficiency, combustion stability, and emissions control.
Mitigation: Iterative design iterations, combined with rigorous testing and validation, can optimize engine performance parameters and ensure compatibility with ammonia injection systems.

4.2.4 Infrastructure and Supply Chain:

Establishing a reliable supply chain for ammonia fuel and retrofitting existing infrastructure require significant investment and coordination among stakeholders.
Mitigation: Strategic partnerships between fuel producers, infrastructure developers, and aviation stakeholders can facilitate the development of ammonia production facilities, storage terminals, and distribution networks to support aviation use.

4.2.5 Regulatory Approval:

Explanation: Ammonia as a fuel for aviation needs regulatory approval to meet safety and environmental standards, requiring thorough testing and certification.
Mitigation: Collaboration between regulatory agencies, industry stakeholders, and research institutions can streamline the certification process and ensure compliance with aviation safety and environmental regulations.
By addressing these feasibility aspects and challenges with appropriate mitigations, the adoption of ammonia injection for thrust augmentation in air-breathing jet engines can be advanced, paving the way for cleaner and more efficient aviation propulsion systems.

4.3 Weight comparing with water-methanol injection

The observed weight difference of approximately 16.14% between ammonia and the water-methanol mixture (1:1 ratio) can be attributed to the inherent variance in their densities. Density, the measure of mass per unit volume, dictates the weight of a substance for a given volume. Ammonia, possessing a lower density than the water-methanol mixture, results in a correspondingly lower weight per unit volume.

As detailed calculations demonstrate, the weight of ammonia is less than that of the water-methanol mixture. This disparity in weight is quantified as a percentage difference, obtained by comparing the absolute difference in weights to the weight of ammonia, and multiplying the result by 100. Thus, the calculated percentage difference highlights the pronounced weight superiority of the water-methanol mixture over ammonia.

In summary, the discrepancy in weight between the two substances underscores the significance of their distinct densities. The higher density of the water-methanol mixture contributes to its greater weight per unit volume, as evidenced by the calculated percentage difference of 16.14%

5. RESULT AND DISCUSSION:

In this study, we investigated the potential of ammonia injection for thrust augmentation in air-breathing jet engines. Our analysis encompassed three key aspects:

5.1 Determination of Disassociation Energy (H) for Ammonia:

Through rigorous research and analysis, we determined that the disassociation of ammonia occurs at a temperature of 622 Kelvin (K). This crucial finding provides insight into the combustion behavior of ammonia, facilitating accurate modeling and prediction of its performance in jet engines.

5.2 Evaluation of Augmented Thrust Percentage:

Our mathematical analysis and experimental validation revealed that the injection of ammonia into the compressor stage of air-breathing jet engines leads to a significant increase in thrust. Specifically, we found that the augmented thrust amounted to 6.58% of the baseline thrust. This finding underscores the effectiveness of ammonia injection as a viable method for enhancing engine performance and thrust output.

5.3 Comparison of Weight between Ammonia and Water-Methanol Mixture:

Additionally, our comparative analysis demonstrated a weight difference of approximately 16.14% between ammonia and water-methanol mixture (1:1 ratio). This disparity highlights the differing densities of the substances and their implications for practical applications in aviation fuel systems.

Overall, our study provides valuable insights into the utilization of ammonia for thrust augmentation in jet engines. The findings contribute to ongoing efforts aimed at developing alternative fuels and propulsion technologies to improve efficiency and reduce environmental impact in the aerospace industry.

6. CONCLUSION & FUTURE SCOPES

6.1 conclusion

In conclusion, our study explored the potential of utilizing ammonia injection for thrust augmentation in air-breathing jet engines. Through comprehensive analysis, we determined key parameters such as the disassociation temperature of ammonia, which occurs at 622 Kelvin (K), and the augmented thrust percentage, found to be 6.58% of the baseline thrust. Additionally, we compared the weight difference between ammonia and a water-methanol mixture (1:1 ratio), revealing a disparity of approximately 16.14%.

These findings highlight the feasibility of employing ammonia as a thrust augmentation agent and underscore its potential to enhance engine performance. By leveraging ammonia's combustion characteristics and considering its weight and density compared to conventional fuels, our study offers valuable insights for the development of alternative propulsion technologies in the aerospace industry. As efforts continue to address environmental concerns and improve fuel efficiency, ammonia injection emerges as a promising avenue for advancing sustainable aviation. Further research and development in this area can lead to significant advancements in engine design and operational strategies, paving the way for a more sustainable future in aviation.

6.2 Future scopes:

In the aerospace industry, the exploration of ammonia injection for thrust augmentation in air-breathing jet engines opens up several promising future scopes

Development of Ammonia-Fueled Aircraft: Aircraft manufacturers can explore the design and development of ammonia-fueled aircraft or retrofit existing aircraft with ammonia injection systems. This includes optimizing engine configurations, fuel delivery systems, and onboard safety features to accommodate the use of ammonia as a propulsion fuel.

Commercialization of Ammonia Injection Technology: Collaborative efforts between engine manufacturers, fuel suppliers, and aerospace companies can lead to the commercialization of ammonia injection technology for widespread adoption in commercial and military aircraft fleets. This involves scaling up production, ensuring supply chain reliability, and obtaining regulatory approvals for ammonia-based propulsion systems.

Integration with Sustainable Aviation Initiatives: Ammonia injection technology aligns with broader sustainability initiatives in the aviation industry, such as reducing greenhouse gas emissions and transitioning to renewable energy sources. Aerospace companies can integrate ammonia injection systems into their sustainability strategies and corporate goals to achieve carbon-neutral or carbon-negative flight operations.

Partnerships and Collaborations: Industry partnerships and collaborations can drive innovation and accelerate the development of ammonia injection technology. This includes collaborations between aircraft manufacturers, engine suppliers, research institutions, and government agencies to share knowledge, resources, and best practices in advancing the technology.

Investment in Infrastructure and Training: Investment in infrastructure development, such as ammonia production facilities, refueling stations, and maintenance facilities, is essential to support the widespread adoption of ammonia-fueled aircraft. Additionally, training programs for aviation personnel, including pilots, maintenance technicians, and ground crew, can ensure safe and efficient operation of ammonia-based propulsion systems.

Market Penetration and Customer Adoption: Aerospace companies can focus on market penetration strategies to promote the adoption of ammonia injection technology among airlines, leasing companies, and government agencies. This involves demonstrating the performance, reliability, and environmental benefits of ammonia-fueled aircraft through pilot projects, test flights, and customer engagements.

By leveraging these future scopes, the aerospace industry can unlock the full potential of ammonia injection technology for thrust augmentation in air-breathing jet engines, ushering in a new era of sustainable aviation powered by renewable energy sources

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REFERENCES

[1] Ali, A. 2001.Macroeconomic variables as common pervasive risk factors and the empirical content of the Arbitrage Pricing Theory. Journal of Empirical finance, 5(3): 221–240.

[2] Basu, S. 1997. The Investment Performance of Common Stocks in Relation to their Price to Earnings Ratio: A Test of the Efficient Markets Hypothesis. Journal of Finance, 33(3): 663-682.

[3] Bhatti, U. and Hanif. M. 2010. Validity of Capital Assets Pricing Model. Evidence from KSE-Pakistan. European Journal of Economics, Finance and Administrative Science, 3 (20).