Plan for Estimating Burn Rate Parameters and Chamber Pressure

Objective

To estimate the burn rate coefficient a and pressure exponent n for a solid rocket propellant using Richard Nakka's simplified method, determine the internal chamber pressure for a 5-grain motor test, and select an appropriate aluminum casing grade based on the results, ensuring robust motor design and performance analysis.

Background and Justification

The burn rate, which dictates how quickly the propellant is consumed, directly influences the rate of gas production and, consequently, the chamber pressure and thrust profile. For amateur rocketry, accurately characterizing the propellant's burn rate is critical to designing a motor that achieves the desired performance while ensuring structural integrity and safety.

The burn rate of a solid propellant is typically modeled using Saint Robert's Law (Vieille's Law):

$$r = aP_c^n$$

where:

- r: burn rate (mm/s)
- a: burn rate coefficient
- P_c: chamber pressure (MPa)
- n: pressure exponent (dimensionless)

These parameters are specific to each formulation (e.g., KNSB) and must be experimentally determined. Chamber pressure is governed by the balance between gas generation (burning surface area A_b and r) and nozzle flow (throat area A_t).

Accurate values of a and n are essential to estimate chamber pressure P_c in a 5-grain motor, influencing the choice of aluminum casing (e.g., 6061-T6) with a safety factor of 1.5.

Nakka's simplified method (burnrate-simple.htm) enables estimating these values using two static tests without requiring strand burners. Supplementary guidance is available at:

- Motor Design
- Burn Rate Test Overview
- Pressure Measurement Guidelines

Plan for Implementation

Number of Tests and Grains per Test

- **Tests**: Minimum of two static firings, each with a different Kn (burning surface area to throat area ratio).
- **Grains**: Use one BATES grain per test for consistency.

Materials Required

- **Grains**: Two KNSB BATES grains (86 mm OD, 33 mm core, 145 mm length)
- **Casing**: Aluminum 6063-T5 tubing (94 mm OD, 3 mm wall)
- **Liner**: 8 layers of epoxy-bonded crafting paper
- **Bulkheads**: Three 6061-T6 aluminum bulkheads with O-ring grooves
- **Nozzles**: Three mild-steel nozzles, throat diameter 23 mm (varied Kn)
- **Ignition System**: Electric igniter (nichrome + pyrogen)
- **Pressure Transducer**: 0–200 Bar range
- **Test Stand**: With 0–8000 N load cell
- **Miscellaneous**: Safety equipment, fittings, grease, microcontroller

Procedure

1. Liner Fabrication:

- Apply epoxy layer-by-layer across 8 crafting paper wraps; cure for 3 days.

2. Grain Casting:

- Cast three identical KNSB grains (65:35 ratio), ensure uniformity.

3. Motor Assembly:

- Machine two mild-steel nozzles (23 mm throat).
- Assemble motor with one grain, bulkheads, and nozzle using O-rings.

4. Test Stand Setup:

- Bolt motor to test stand securely.
- Install pressure transducer as per Nakka's guidelines.
- Connect sensors to microcontroller with data logging.

5. Static Test Execution:

- Perform two tests in an outdoor location (e.g., baseball pitch).

- Record pressure and thrust throughout burn.
- Use remote ignition and follow all safety protocols.

6. Data Collection:

- Record chamber pressure P_c vs. time
- Record burn time and thrust
- Measure grain pre-/post-burn dimensions (web thickness)
- Note nozzle erosion (diameter change)

Data Points to Collect

Per Test

- Chamber pressure $P_c(t)$
- Burn time
- Grain geometry (before/after)
- Nozzle throat diameter (before/after)
- Thrust vs. time

Derived

- Burn rate r
- Kn value
- Burn rate coefficient a
- Pressure exponent n
- Estimated chamber pressure for 5-grain motor

Summary Documentation

Two static tests using single BATES grains will estimate burn rate parameters a and n through Nakka's simplified method. Chamber pressure data will allow extrapolation for a 5-grain design. Tests will use 6063-T5 casings, mild-steel nozzles, and follow proper pressure instrumentation guidelines. Results will inform whether 6061-T6 or 7075-T6 casing is required.

Safety Considerations

- Conduct tests outdoors with blast shielding
- Use PPE (safety glasses, gloves, FR clothing)
- Verify transducer and load cell calibration
- Follow Nakka's pressure measurement protocols

Conclusion

This plan outlines a structured approach to experimentally determine burn rate parameters and internal pressures for solid motors. By using Nakka's method and ensuring rigorous construction and testing practices, the team can build a reliable 5-grain rocket motor suitable for future high-performance applications.