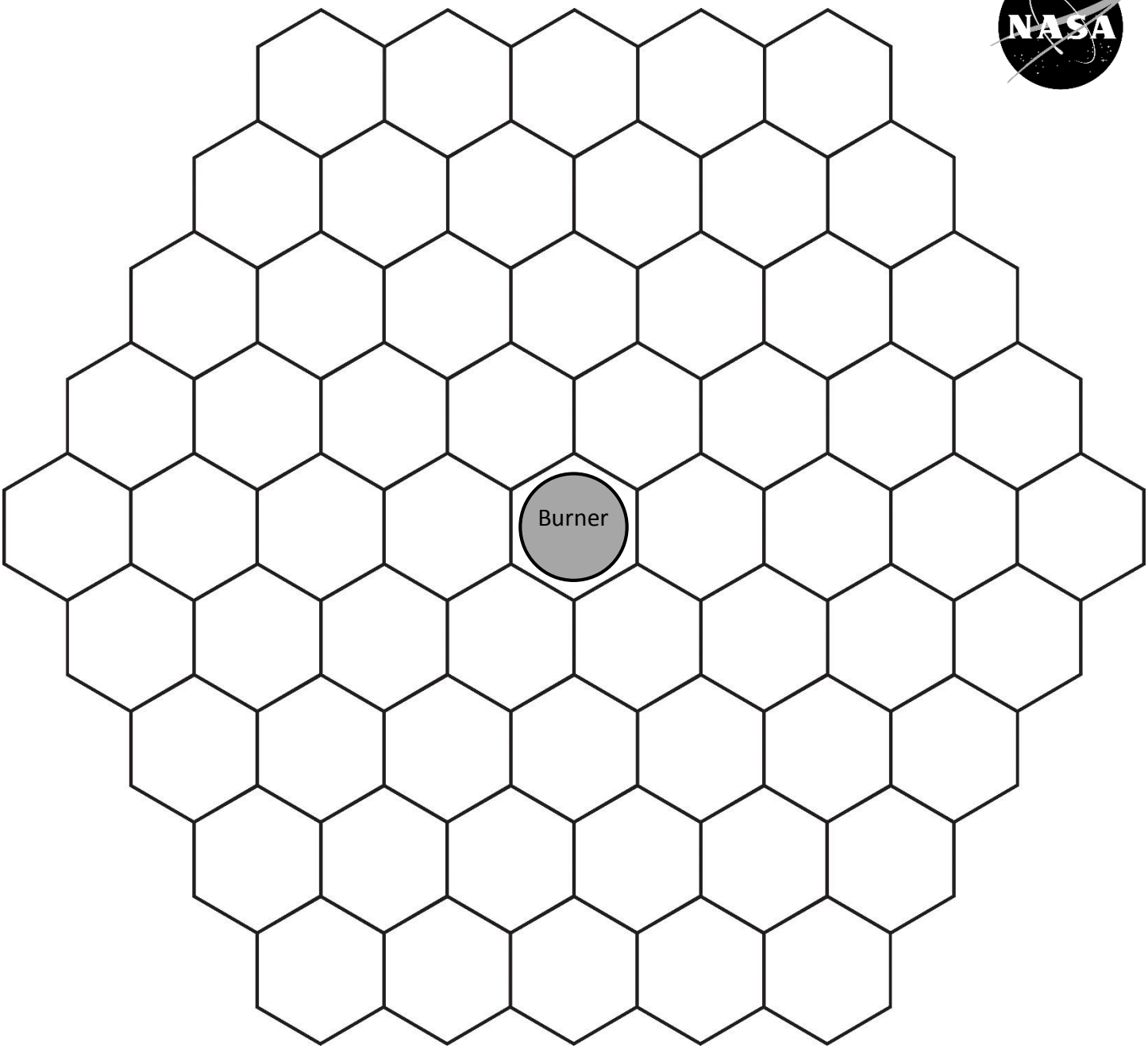
ACME Flame Game



Fuel Consumed

1	2	3	4	5	6	7	8	9

Rules Summary

- The fuel player always goes first and plays 1 piece per turn, while the oxygen player plays 2 pieces per turn.
- Reactions immediately occur when a fuel piece becomes adjacent to 2 non-adjacent oxygen pieces. The 3 pieces are removed and the removed fuel piece is placed on the 'Fuel Consumed' track above.
- The game ends when 9 fuel pieces are consumed.
- The fuel player's score is the number of fuel pieces remaining on the hexagonal field at the game's end.
- Play the game twice if possible, where each player plays both sides. The player with the highest fuel score wins.

ACME Flame Game

The 2-player board game simulates a spherical microgravity flame. One player takes the role of the gaseous fuel and tries to make the flame as large as possible. The other player has the role of the oxygen and strives to keep the flame as small as possible.

- *NASA's ACME project includes two experiments using spherical flames, which are normally only possible in microgravity, where there seems to be no up or down (so hot gases don't naturally rise). The one-dimensional symmetry dramatically simplifies the analysis, e.g., greatly facilitating detailed computational modeling.*

Materials

In addition to the board and this rule sheet, both players need a set of 20 playing pieces which are easy to pick up, such as cube-shaped alphabet beads or small dice. While less convenient, folded strips of paper can also be used as described in the included template. The two sets must be distinguishable, e.g., differ in color, shape, or size.

- *The playing pieces represent the fuel and oxygen molecules.*

Rules

Sequence: The two players alternate turns, where the fuel player always goes first and plays 1 piece per turn, while the oxygen player plays 2 pieces per turn.

- After the oxygen player's turn, there should always be twice as many oxygen pieces on the board as fuel pieces … with the possible exception of the last turn.

Fuel placement: Fuel pieces are placed in empty spaces adjacent to either the burner (space) or another fuel piece that is already on the board.

- *The gaseous fuel moves outward from the burner because of both the forced fuel flow and diffusion.*

Oxygen placement: Oxygen pieces are placed in empty spaces adjacent to either the edge of the hexagonal board or another oxygen piece that is already on the board. Don't forget that the oxygen player places 2 pieces per turn!

- *The oxygen diffuses inward (because of its concentration gradient) toward the flame.*

Burner: The center space is occupied by the burner and no pieces can be played upon it.

Combustion: If the placement of any piece makes a fuel piece adjacent to two non-adjacent oxygen pieces, then the fuel and oxygen react and those three pieces are immediately removed from the board. The removed fuel piece is placed in the first open space in the 'Fuel Consumed' track. The removed oxygen pieces are returned to the oxygen player for re-use during the game.

- If the placement of the first oxygen piece in a turn causes a reaction, then the 'consumed' pieces are removed before the second oxygen piece is played.
- If there is more than one combination of pieces that would react, the player who caused the reaction (i.e., by placing the third piece) chooses which combination of pieces to remove.
- *The game specifically represents the combustion of methane which is the primary component of natural gas. Methane is used extensively in ACME because its chemistry is well understood. It is simulated in the game because two oxygen molecules are required for the complete combustion of each methane molecule.*

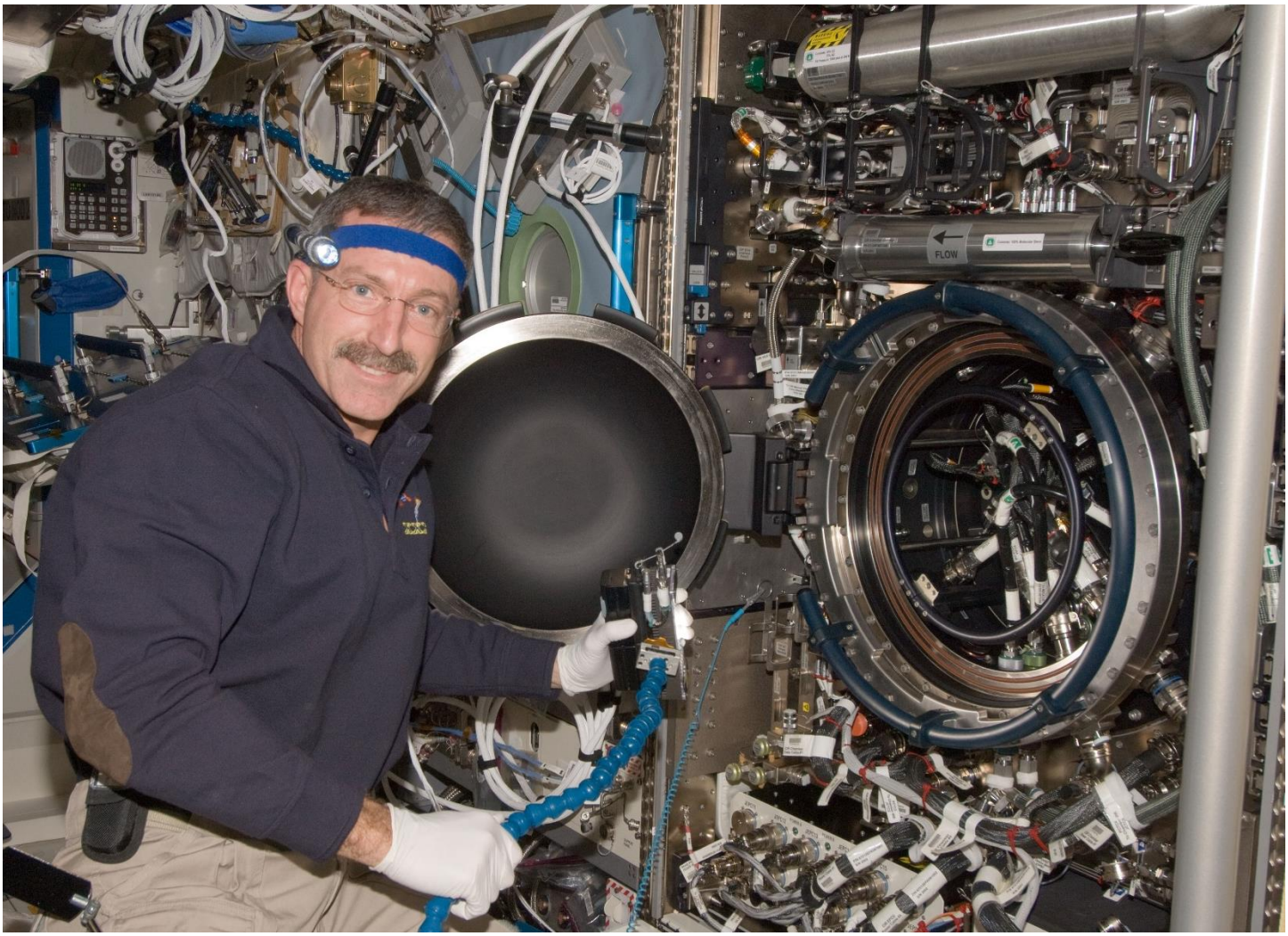
End of game: The game immediately ends when 9 fuel pieces are consumed.

Scoring: The fuel player's score is the size of the flame, as determined by counting the number of fuel markers on the hexagonal field at the game's end.

Switch sides and play again! This game should be played twice if possible, where each player plays both sides. The winner is the player who scored highest as the fuel.

Background

ACME: The primary goal of the Advanced Combustion via Microgravity Experiments (ACME) project is to improve efficiency and reduce pollutant emission in practical terrestrial combustion. A secondary objective is fire prevention, especially for spacecraft. ACME includes five independent experiments that will be conducted using modular hardware in the Combustion Integrated Rack (CIR) facility on the International Space Station (ISS). An ACME precursor, the Structure & Liftoff In Combustion Experiment (SLICE), was already conducted on ISS in 2012.



NASA astronaut Dan Burbank working on the ISS's Combustion Integrated Rack (CIR) during Expedition 30. The CIR's cylindrical combustion chamber is open and experimental hardware can be seen inside.

Board: The game board's hexagonal field represents the circular cross-section of the CIR's cylindrical combustion chamber.

Burner: The game simulates the spherical flames in ACME's Flame Design and s-Flame experiments, in which gaseous fuel flows from a porous spherical burner into a chamber filled with a mixture of oxygen and an inert gas, such as nitrogen. However, some tests will be conducted in a reverse configuration where the chamber is filled with a fuel/inert mixture and an oxygen/inert mixture flows from the burner. An example flame, from the s-Flame experiment, can be seen in the photograph to the right, where the dark circle in the center is the burner (which is fed gaseous fuel through a narrow tube, which is also

Spherical flame from the s-Flame experiment.

visible). These spherical flames can normally only be created in microgravity where there is no buoyancy to cause the hot combustion gases to rise.

Placement: The placement of the playing pieces represents the radial motion of the gaseous fuel and oxygen. For a normal flame, as represented in the game, the fuel flows radially outward from the porous spherical burner because of both forced flow and molecular diffusion, i.e., where the molecules move from a high concentration to a lower concentration. Meanwhile, the atmosphere in the chamber is still and the oxygen diffuses inward toward the flame, again because of the concentration gradient.

Flame: The flames in all of the ACME experiments are classified as non-premixed, which means that the fuel and oxygen are initially separated rather than mixed. A candle flame is a common example of a non-premixed flame, where the vaporized fuel is within the flame and the oxygen is outside of it. The flame is a thin sheet, separating the fuel and oxygen, and is where the two species meet, react, and emit heat, light, and combustion products such as carbon dioxide and water vapor. The sheet is thin because the combustion reactions take place much more quickly than the diffusive mixing of the reactants. Meanwhile, inert gases like the nitrogen (which makes up nearly 80% of the Earth's atmosphere) cross through the flame.

Spherical flame from the Flame Design experiment.

Reaction: The flame is positioned where the fuel and oxygen come together in a stoichiometric ratio. The game simulates the combustion of methane, which is primary component of natural gas and therefore of tremendous practical importance. But more importantly for ACME, the chemical reactions of this simple molecule are well understood making detailed computational studies of the flame practical. Methane is simulated in the game because two oxygen molecules are required for the complete combustion of each methane molecule. ACME also makes extensive use of ethylene which tends to produce much more soot because of its double bond which makes the fuel a good building block for soot precursors. Each ethylene molecule requires three oxygen molecules for complete combustion and its combustion could be simulated in the game with appropriate changes. However, the provided game board is too small for playing three oxygen pieces per turn to account for the ethylene stoichiometry.

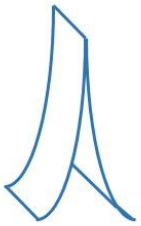
Consumption: The ACME tests are conducted in a sealed combustion chamber which is much larger than the flame. Nonetheless, the atmosphere does change through the duration of a test. Fuel flows into the chamber which is consumed in the flame, increasing the pressure and temperature, producing carbon dioxide and water vapor, and decreasing the oxygen. To limit those changes, the ACME tests are limited to a short duration, typically lasting between 30 to 120 seconds. The test duration is simulated in the game by tracking the fuel consumption, where the fuel flows at a constant rate in most ACME tests.

Creators: This educational game was created by the ACME Project Scientist, Dennis P. Stocker (of the NASA Glenn Research Center), and Raymond Crowder III who worked as an undergraduate intern on the ACME project in the fall of 2014. Will Stocker and Amanda Bosley contributed as playtesters.

Website: http://spaceflightsystems.grc.nasa.gov/acme/

Playing Piece Template

Both players need a set of 20 playing pieces which are easy to pick up, such as cube-shaped alphabet beads or small dice. While less convenient, pieces can be cut using this template, where a thicker stock may make superior playing pieces. After folding the pieces in half, the base should be flared (or folded) outward as shown in the figure at the right. Of course, the two sets must be distinguishable, where they are labeled F for fuel and O for oxygen. This template makes enough pieces for two sets.



F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F

O	O	O	O	O	O	O	O	O	O	O	O
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