U.S. AIR FORCE

USSF

AFRL

# DYNAMIC BREATHING SIMULATOR

## BIOMEDICAL IMPACT OF AIR & SPACE

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Aerospace Physiology Research

# Overview

- Oxygen → Cognition and Performance
- Flight Profiles → Influence Pilot Breathing
- Researchers → Anticipate Flight Parameters

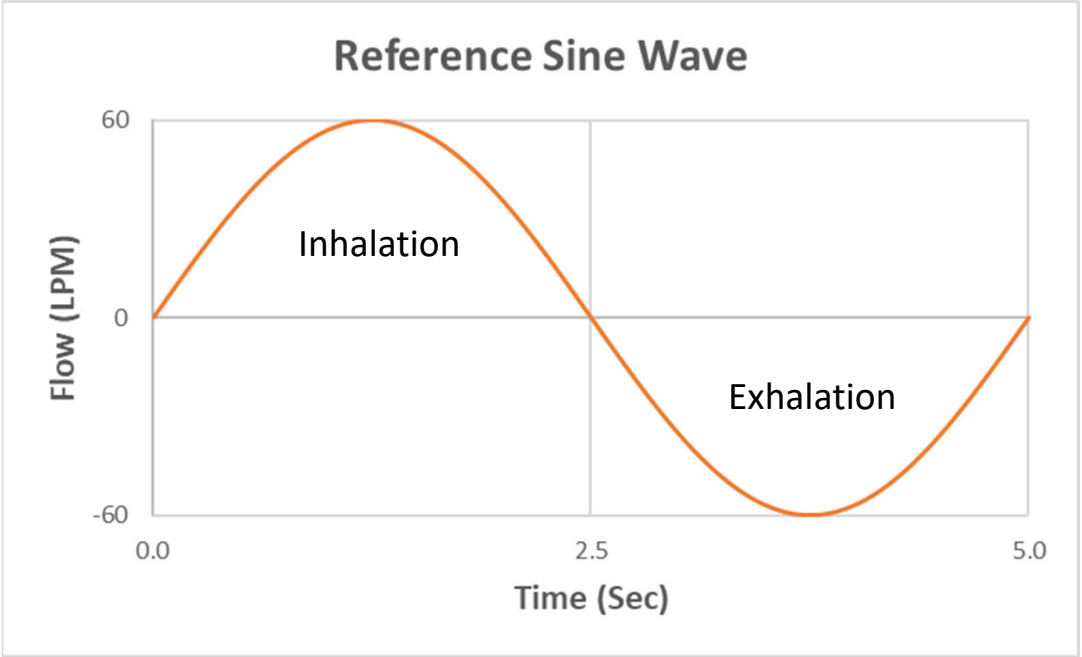
**Dynamic Breathing Simulator**

→ Create Advanced Algorithms for Replicating Pilot Breathing

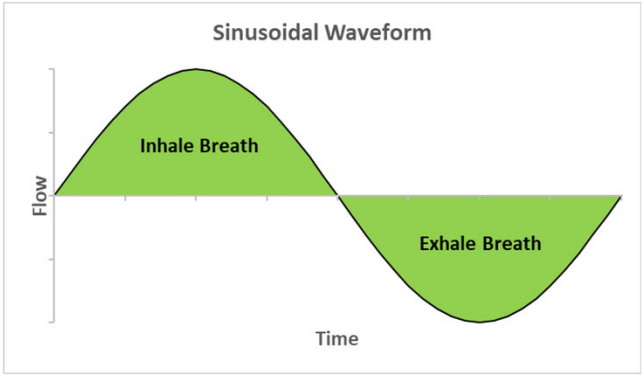
*Helping Save Pilots... One Breath at a Time*

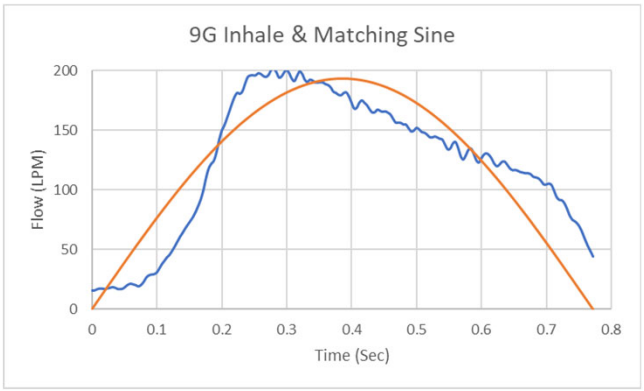
# Pertinent Terms

- Tidal Volume (TV):
  Amount of Air Inhaled per Breath
  (Resting ~ 0.5 Liters)
- Breathing Rate (BR):
  Number of Breaths per Minute
  (Resting ~ 12 BPM)
- Minute Ventilation (MV):
  Volume of Air Inhaled per Minute (Resting ~ 6 LPM)




*Note: Summation of Inhale Volumes = Summation of Exhale Volumes*




# Design Goals

## Human Breathing Characteristics

| Tidal Volume: | Respiratory Rate: | Gas Peak Flow: |
|---|---|---|
| Max: ~ 3-4 L | *Max: ~ 100 BPM | *Max: ~ 320 LPM |
| Typical: ~ 0.5 L | Typical: ~ 12-20 | Typical: ~ 60 LPM |

*MIL-STD-3050A

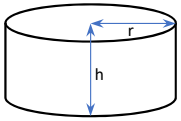
## Breathing Simulator Characteristics

| Bellows Volume: | Cycle Rates: |
|---|---|
| Max: ~ 4 L | Determined by combinations of LPM & BPM |

# Mechanical System

- Bellows (Volumetric Air Flow):

$V = \pi r^2 h$



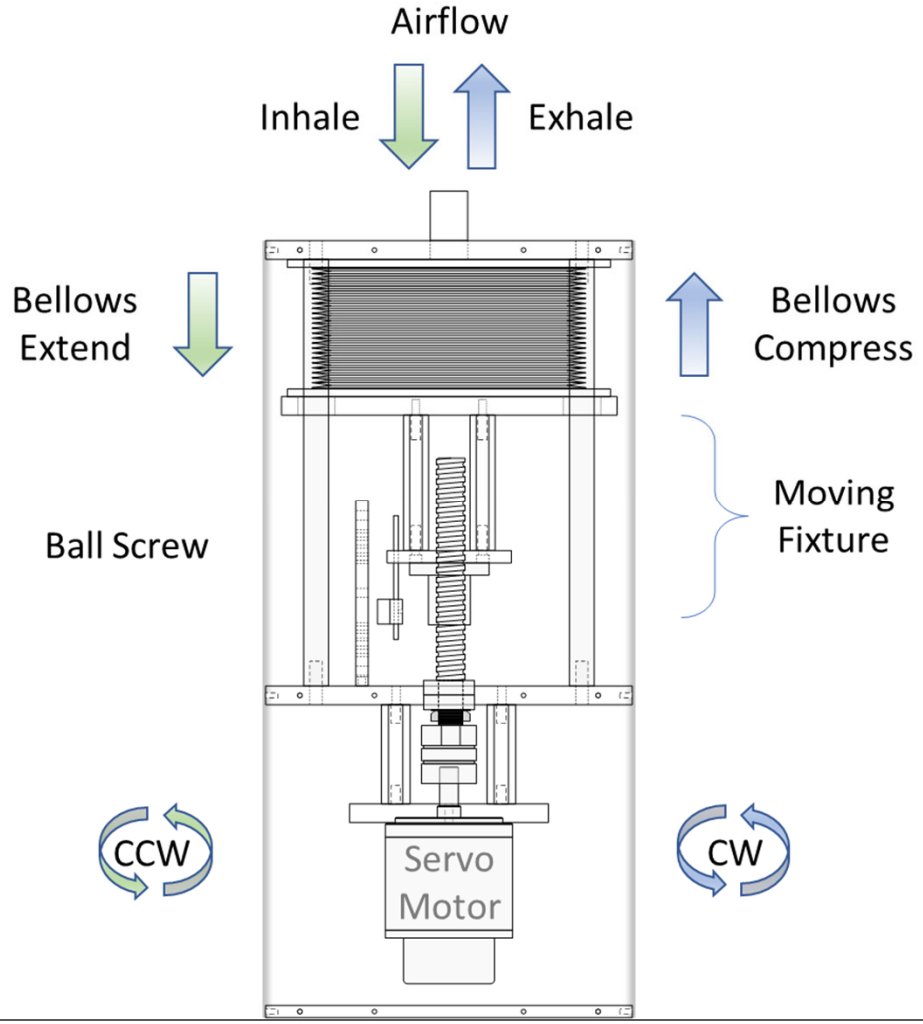

*h* = stroke, *r* = radius = ~ 5 inch

- Ball Screw (Linear Displacement):

  5 revolutions = 1 inch of travel

- Servo Motor (Rotary Motion):

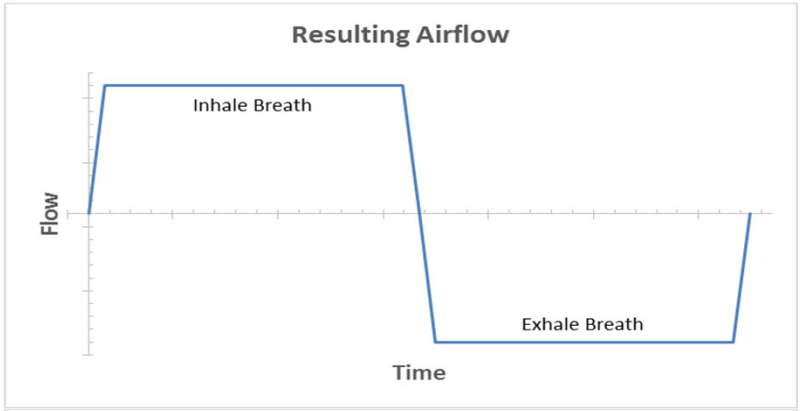
  Encoder: ~ 8K counts/revolution

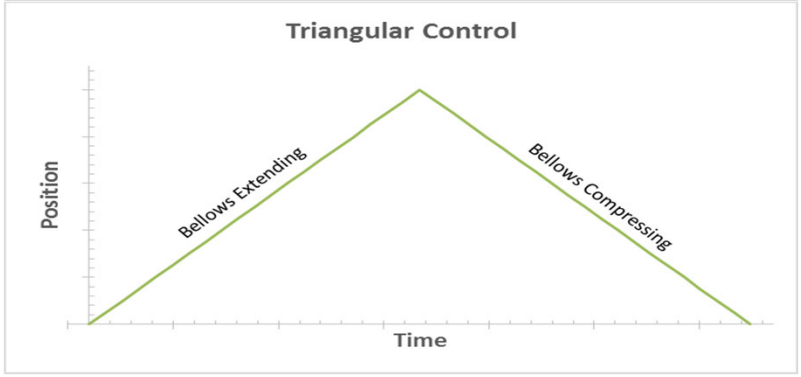


# Basic Motion

Inhale Airflow

Bellows Extend

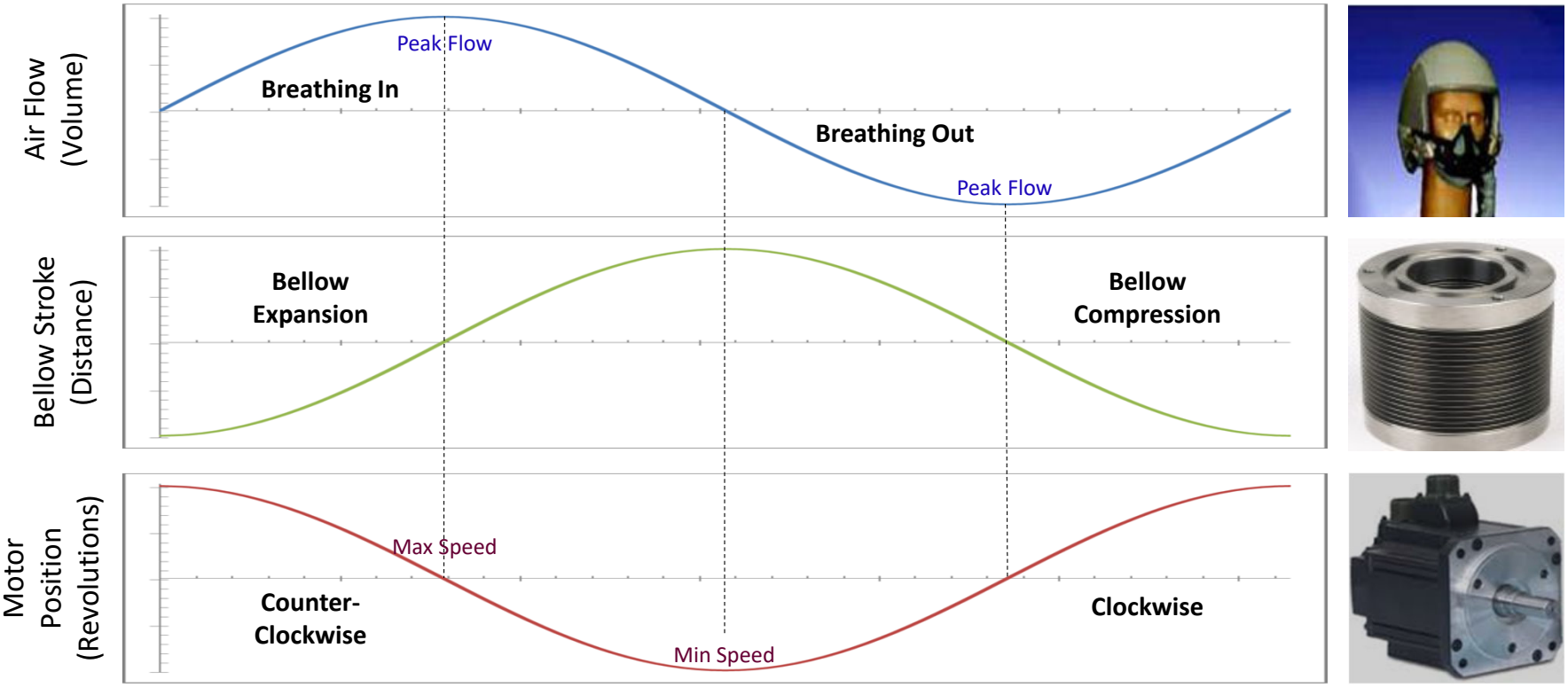



Exhale Airflow

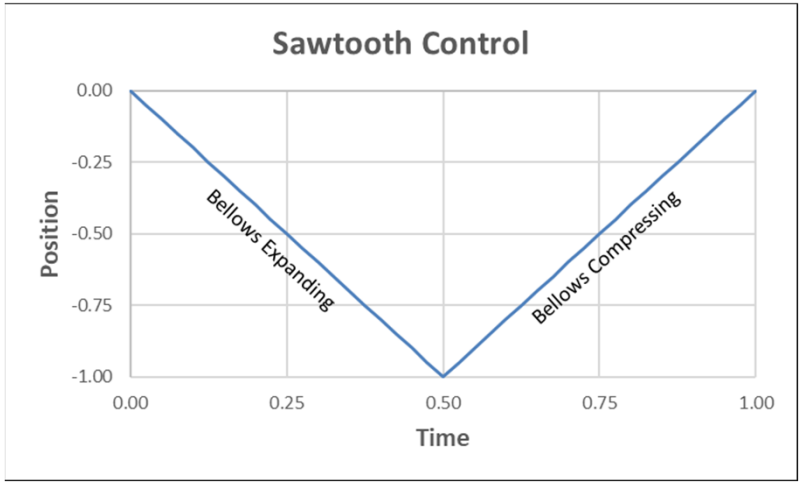
Bellows Compress

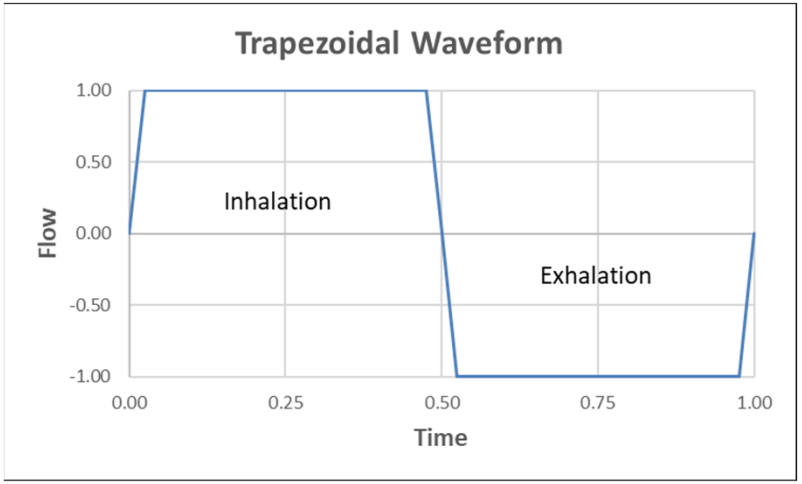
# System Correlations



# Sawtooth Algorithm

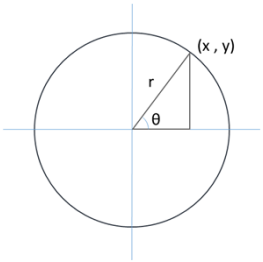
- Basic Motion Waveform
- Equation: y = mx +b
- Run at Slow Speeds
  - Provides steady air flow
  - Verify sensor data
- Run at High Speeds
  - Abrupt motion transitions
  - Investigate cellular shear
- System Checks or Maintenance

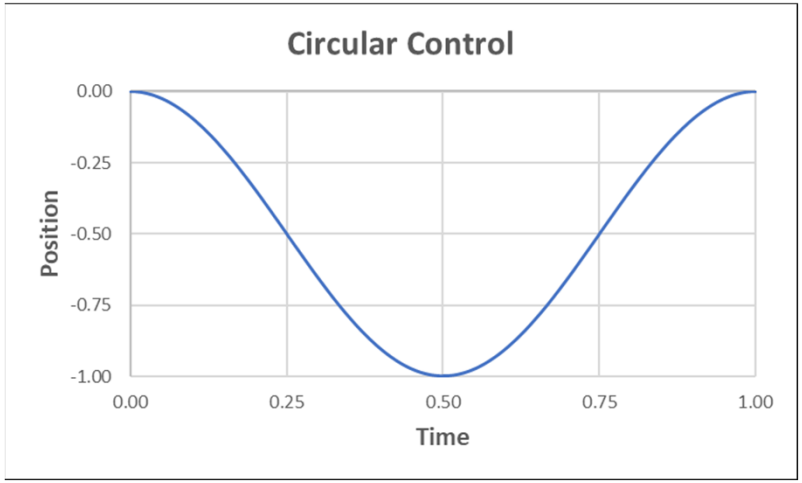


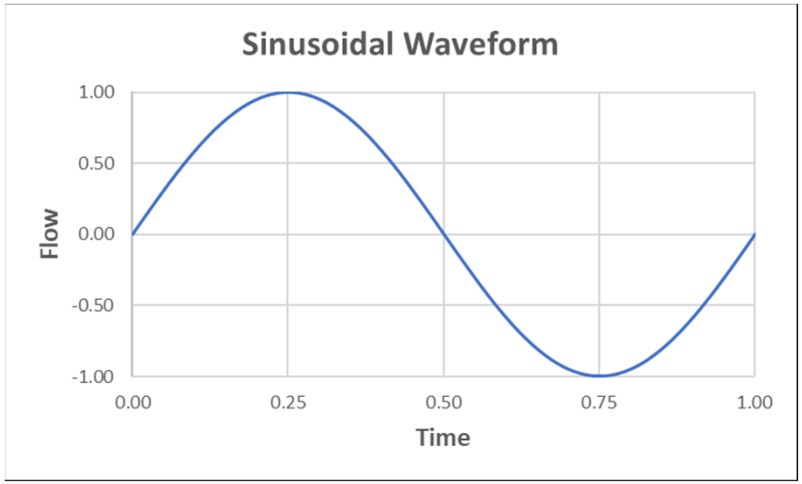



# Circular Algorithm

- Industry Standard Waveform
- Equation: y = a * sin(bx + c)
  - Circle: x = r cos(θ) and y = r sin(θ)
  - Real and Virtual Axis Assignments
- Circular Velocity -> Peak Air Flow
- Circumference -> Time per Breath
- Rapid Transitions Between Profiles
- Allows Pause & Duty Cycle Options

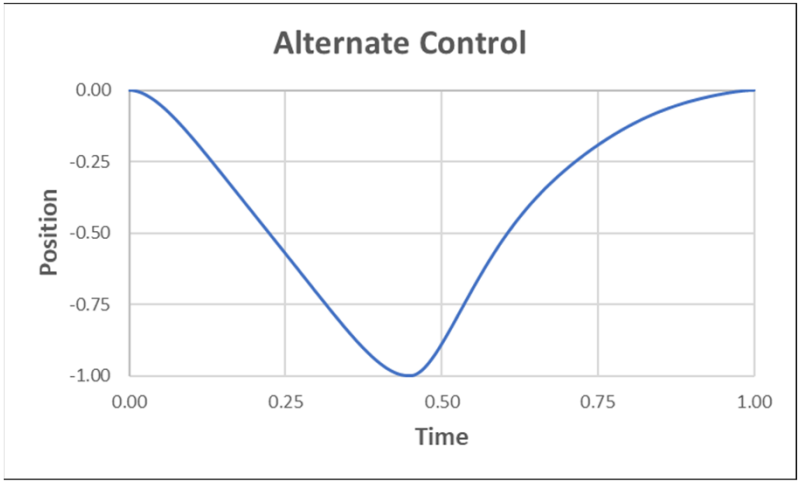


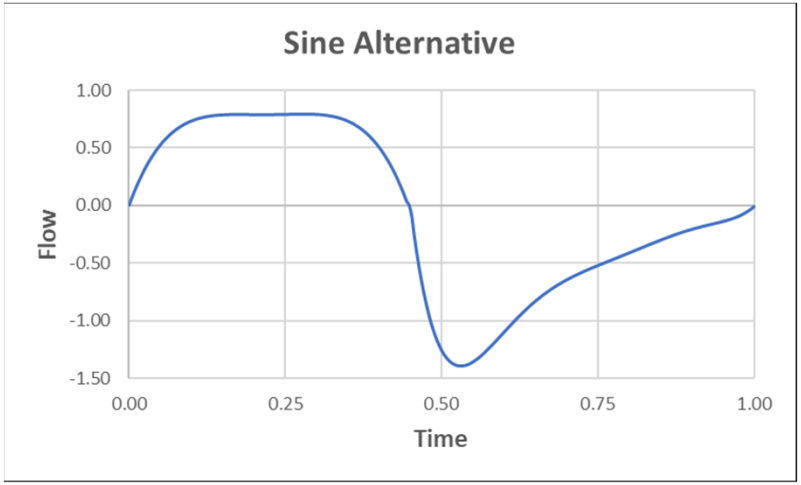



# Alternate Algorithm

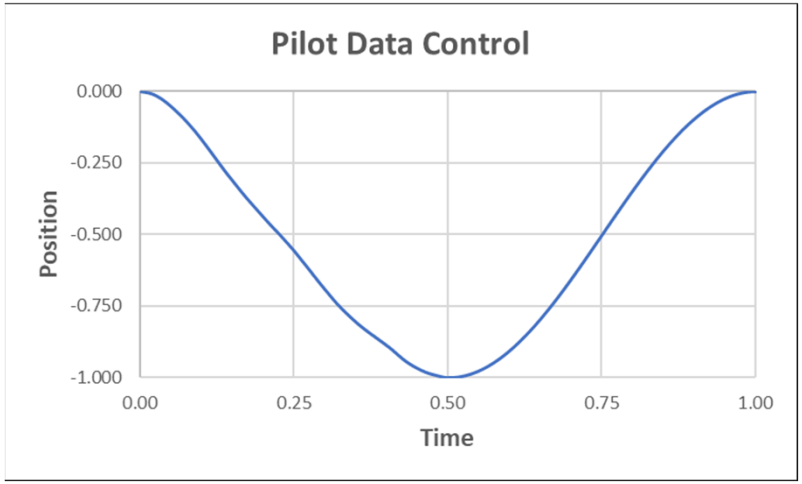
- Approximation of Human Breathing
  - Dr. Dan Warkander (NAMRU-Dayton)
  - Based on Centrifuge Data
  - Supports Higher G Breathing (5-7-9)
- Volumetric Flow Considerations
- Inhale Waveform:
  - Increased Section of Steady Flow
  - Duty Cycle Typical ~ 45%
- Exhale Waveform:
  - Exponential Flow
  - Duty Cycle Typical ~ 55%

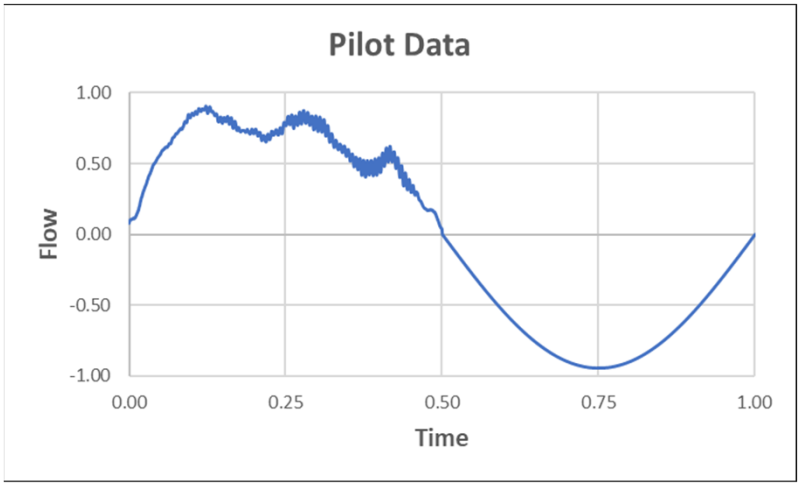


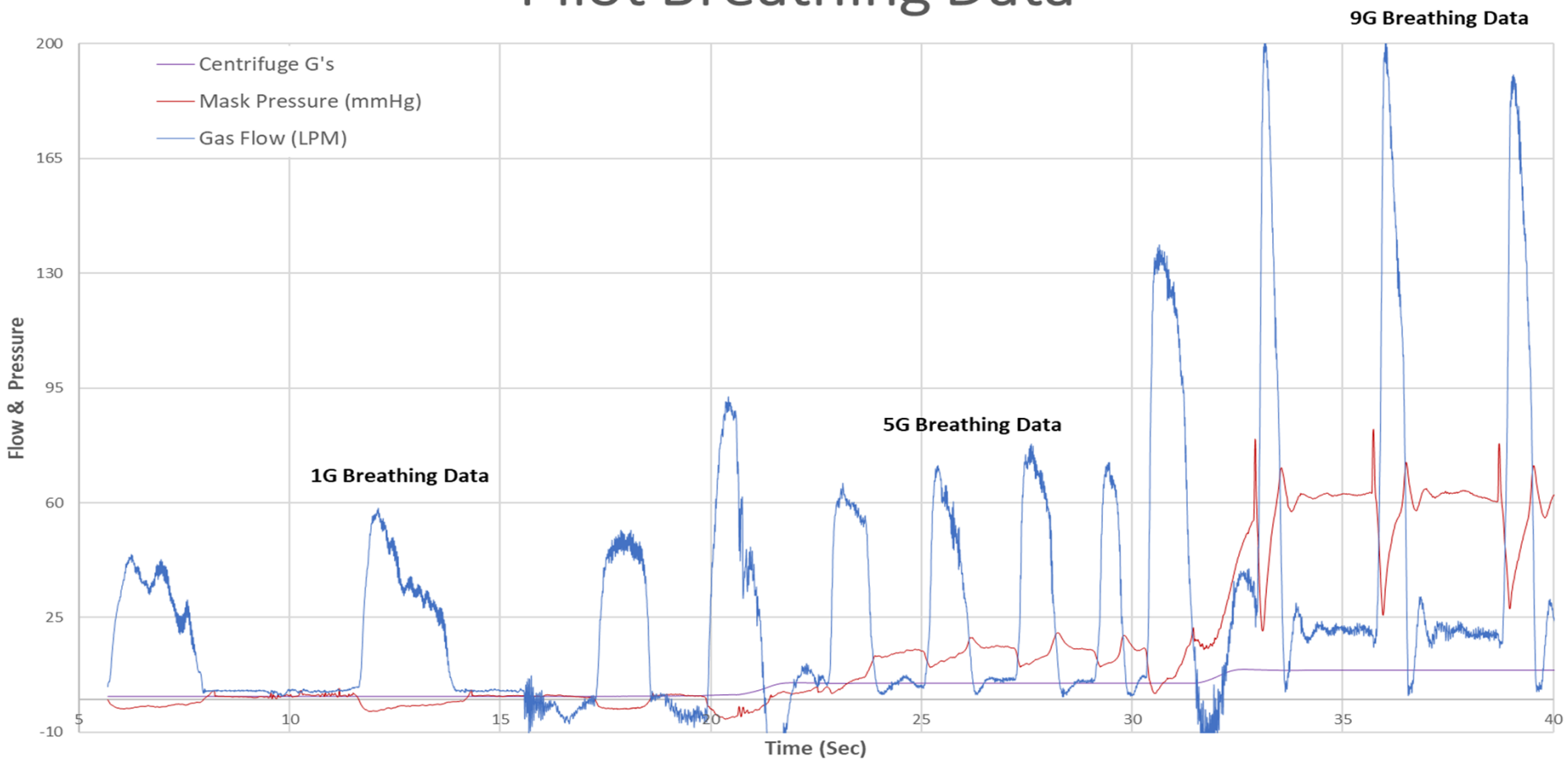
# Pilot Data Algorithm

- Replication of Human Breathing
  - Centrifuge Run Data (1G, 5G, 9G)
  - Inhale Matches Exhale Volume
- Opportunities
  - Reproduce Flight Profile Breathing
  - High Fidelity System Simulations
- Challenges
  - Recording Actual Flight Mission Data
  - Exhale Vented Through Mask
  - Pilot Performance Sensitivities

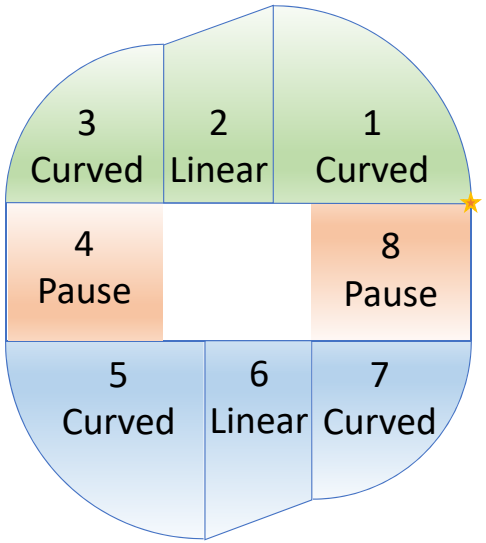


# Pilot Breathing Data

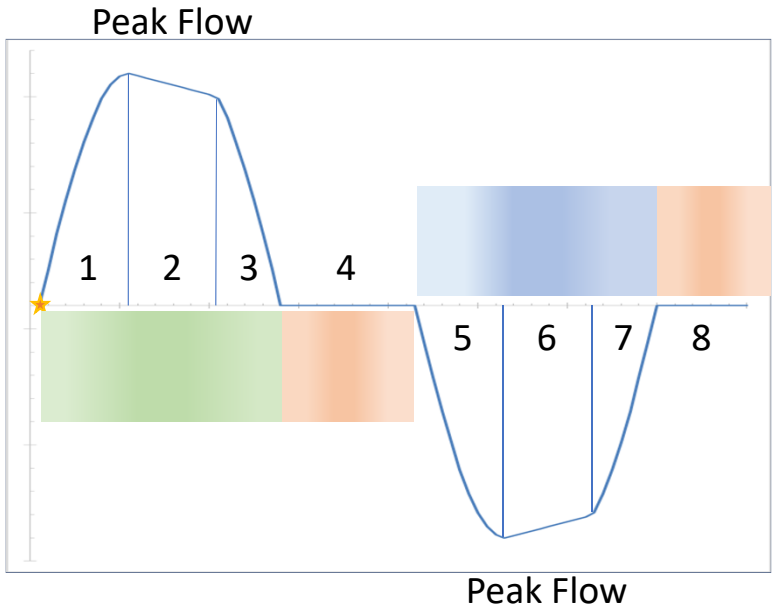


# Building Waveforms




Inhale

Exhale

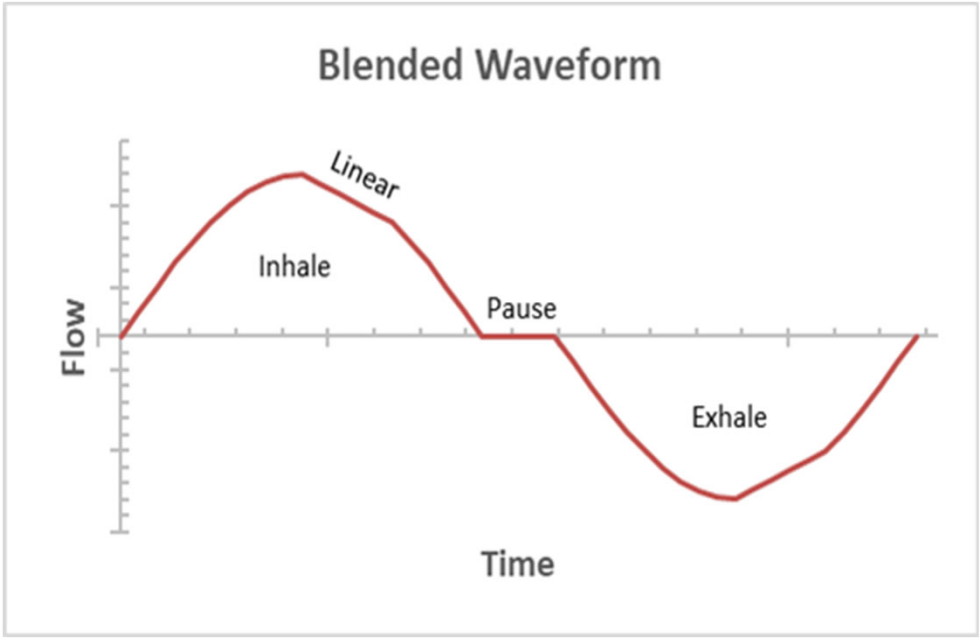




# Blended Waveform

- Research Attributes
  - Combine Building Blocks
  - Create Unique Wave Patterns
- Algorithms to Match Actual Data
  - Repeatable and Scalable
  - Supports Automations
- Simulate Custom Profiles
  - Separate Inhale and Exhale Wavelets
  - Blend Data and Algorithms





# MIL-STD-3050A

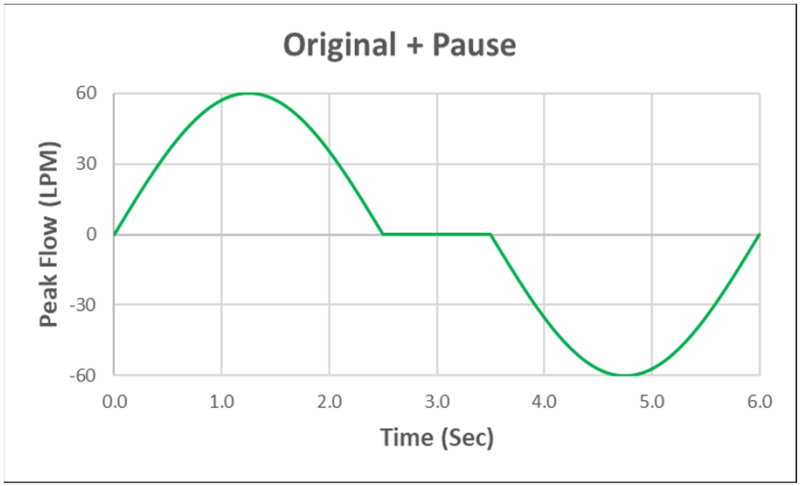
→ Pause
→ Duty Cycle

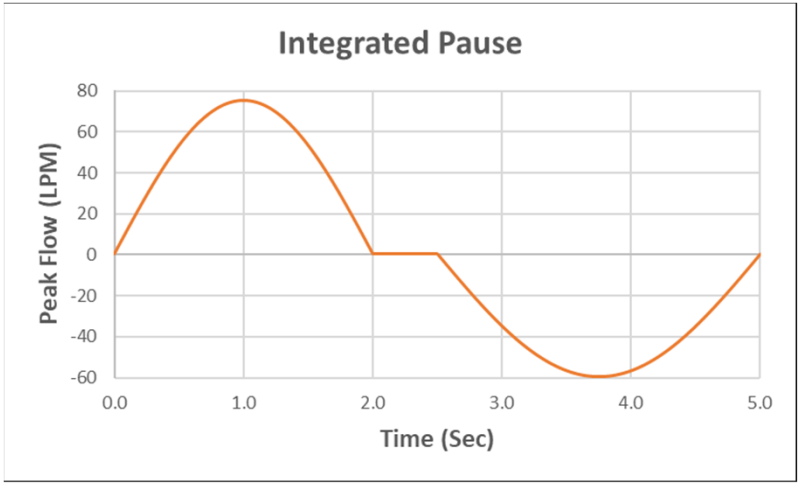
| MIL-STD-3050A Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Test Condition | Mean (LPM) | Peak (LPM) | Tidal (L) | Freq (BPM) | | | | |
| 1 | 10 | 31 | 1 | 10 | | | | |
| 2 | 20 | 63 | 1 | 20 | | | | |
| 3 | 30 | 94 | 1.5 | 20 | | | | |
| 4 | 35 | 110 | 1.5 | 23.3 | | | | |
| 5 | 40 | 126 | 1 | 40 | | | | |
| 6 | 50 | 157 | 2 | 25 | | | | |
| 7 | 60 | 188 | 2.5 | 24 | | | | |
| 8 | 65 | 204 | 2 | 32.5 | | | | |
| 9 | 75 | 236 | 1.5 | 50 | | | | |
| 10 | 75 | 236 | 2.5 | 30 | G's | Inhale % | Pause % | Exhale % |
| 11 | 41.6 | 180* | 1.6 | 26 | 5 | 36 | 28 | 36 |
| 12 | 52.5 | 258* | 1.75 | 30 | 7 | 32 | 36 | 32 |
| 13 | 34.5 | 322* | 1.5 | 23 | 9 | 18 | 64 | 18 |
| | | *Exception to Previous Trend: Peak Flow = Pi x Mean | | | | | | |

# Pause Options

- Pause After Wavelet Segments
  - Original Waveform + Pause (1 Sec)
  - Constant Peak Flow (60 LPM)
  - Constant Wavelet Timing (2.5 Sec)
- Wavelets with Integrated Pause
  - Original Frequency (12 BPM)
  - Shorten Wavelet Time (2.0 Sec)
  - Increase Peak Flow (75 LPM)

→ *Maintain Constant Tidal Volume*



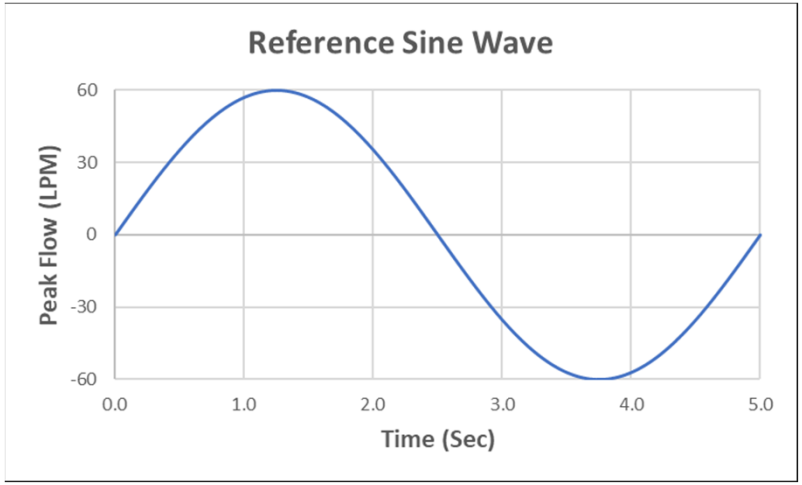


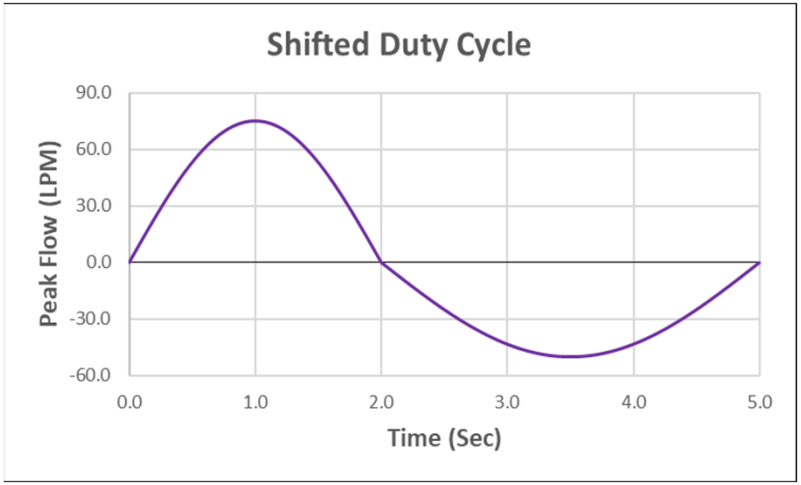

 

# Shifted Duty Cycle

- Adjust Peak Flow & Wavelet Time
- Reference Sine Wave
  - Both Wavelets: 60 LPM & 2.5 Sec
  - Tidal Volume: 1.6 Liters
- Shifted Waveform
  - Inhale Wavelet: 75 LPM & 2.0 Sec
  - Exhale Wavelet: 50 LPM & 3.0 Sec
  - Tidal Volume: 1.6 Liters

→ *Maintain Constant Tidal Volume*





# Summary

- So, how's your breathing?

Energetic – Excited – Focused – Relaxed

- Do you breathe in circles or are you more like a square?

- Dynamic Breathing Simulator…

→ Saving Airmen…

One Breath at a Time