# GAMA PUBLICATION NO. 16

# HYBRID & ELECTRIC PROPULSION PERFORMANCE MEASUREMENT



Version: 1.0
3.February.2017

## Preface

To assure common taxonomy and to assist in the operational expectations of aircraft utilizing hybrid & electric propulsion, the Electric Propulsion Innovation Committee (EPIC) of the General Aviation Manufacturers Association has developed Publication 16, *Hybrid & Electric Propulsion Performance Measurement.*

The General Aviation Manufacturers Association (GAMA) is a global trade association representing over 90 of the world's leading manufacturers of general aviation airplanes and rotorcraft, engines, avionics, components and related services. GAMA's members also operate repair stations, fixed based operations, pilot and maintenance training facilities and they manage fleets of aircraft.

From its start in 1970, GAMA has been devoted to one primary purpose: *to foster and advance the general welfare, safety, interests and activities of general aviation*. This includes promoting a better understanding of general aviation and the important role it plays in economic growth and in serving the transportation needs of communities, companies and individuals worldwide.

Headquartered in Washington DC, USA, with an office in Brussels, Belgium, GAMA represents the interests of its members to government agencies throughout the world. These interests include legislation, safety regulations and standards, market access, development of aviation infrastructure, and aviation security.

Through its public information and education programs, GAMA promotes better understanding of general aviation and the important role it plays in economic growth and in serving the transportation needs of communities, companies and individuals worldwide.

One of GAMA's objectives is to foster the development of industry publications and best practices to enhance aviation safety through standardization. This publication was developed to aid manufacturers and operators in the common determination of hybrid & electric aircraft performance measurements. Through the establishment of this common set of global measures for hybrid & electric propulsion, the aviation community will have a standardized perspective from which to measure aircraft which utilize hybrid & electric propulsion.

Questions on interpretation and proposed changes to this publication (including requests to provide additional clarification or scenarios) should be submitted to General Aviation Manufacturers Association, Suite 801, 1400 K Street, N.W., Washington, D.C. 20005 or emailed to comments@gama.aero.

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# 1.0 General

The operational characteristics of aircraft which utilize hybrid & electric propulsion (including hybrid systems) are unique as compared to traditional combustion engines. To take full advantage of the benefits of hybrid & electric propulsion these designs employ unique systems and aerodynamic solutions which result in aircraft that fulfill transportation, training, sport and leisure flying missions in a manner that may be historically different.

GAMA Publication 16 has been structured to address typical operational scenarios for hybrid & electric aircraft. The document also provides symbolic messages which can be useful in marketing or for illustration purposes when documenting the capabilities of various hybrid & electric aircraft in operating information.

This document provides performance measurements so manufacturers and consumers can work from a common frame of reference across products utilizing hybrid & electric propulsion but GAMA does not measure the performance of aircraft to verify any claims of meeting the standards provided in this publication. Good standardization of range and performance information will be helpful in assuring the long-term success of hybrid & electric propulsion use in aviation so consumers clearly understand what the products are capable of at a common frame of reference.

## 1.1 Objective

This publication is intended to provide standard performance measures for aircraft which utilize hybrid & electric propulsion across various scenarios. The publication provides standardization measures for use by both manufacturers and consumers. While it is possible that revisions to this document will be necessary as more operational experience is gained with hybrid & electric propulsion, it is an objective to minimize changes to existing operational standards once they have come into use.

## 1.2 Scope

The scenarios and measurements contained in this document are intended to capture typical hybrid & electric aircraft operations. Because the field of hybrid & electric aircraft propulsion is growing rapidly at the current time, it is conceivable that new scenarios or changes to existing scenarios may occur as experienced is gained in the future.

## 1.3 Publication Change Management

All changes to this publication will be indicated by a change bar in the left margin of the document and will remain until the next revision. Each page will also display the revision number at the top of the document in the header section. Document revisions will be tracked in the records of revisions section, while a revision status list of each page will be tracked in the list of effective pages section of this document.

# 2.0 General Consistency in Performance Measurements

GAMA has identified a number of typical mission profiles that are common among hybrid & electric aircraft. To facilitate a common understanding of how to categorize and measure the performance of these aircraft, the following scenario based missions can be used. Some aircraft may be designed for independent missions while others may be designed to accomplish a range of missions.

All performance measurements are calculated on a standard day (from sea level, 29.92 in/Hg at 15 °C or 59 °F with standard lapse rate) with no wind. It is acceptable to calculate standard day no wind performance based upon correlated data.

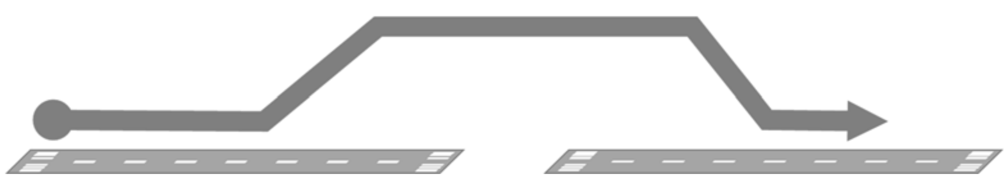
These measurements are performed using worst case batteries (end of life operational in the case of Li Ion) or the performance measurements can be analytically corrected to reflect an end of life operational quantity of energy. Each performance measurement (2.1, 2.2, 2.3 & 2.4) is meant to be indicative of a possible operation on an individual aircraft.

Any or all of the performance measurements may be declared for a single aircraft type. For example, one may indicate information related only to the destination trip (2.1) or one may choose to indicate information related to measures 2.1, 2.2, 2.3 & 2.4 or any combination thereof.

All performance information within each performance measurements need not be declared when illustrating the performance of an individual aircraft type. For example one indicating performance measurements related to the destination trip 2.1 can include any combination of the performance measures (cruise time, cruise speed, trip distance, etc.).

## 2.1 Destination Trip (A to B Transportation)

The destination trip simulates a transportation activity between two non-towered regional airports with a 2,000 ft. obstacle in between them. The total energy required for the trip includes normal preflight including checks, taxi, takeoff, climb, cruise, descent, landing, normal shutdown and reserve energy. When following the standard for a destination trip as detailed below, the distance between airports, time between airports, cruise speed & time, and/or refuel (recharge) time are variables that can be measured and provided.



Cruise Time: xxxxx (min.)
Trip Distance: xxxxx (NM)
Refuel Time: xxxxx (min.)
Total Payload: xxxxxx (lbs.)

Cruise Speed: xxxxx (KTAS)
Flight Time: xxxxx (min.)
Total Energy: xxxxx (KWh)

**Airport Altitude (departure and destination):** Sea Level (0 ft)
**Conditions:** ISA / no wind
**Runways:** Hard smooth surface
**Pre-Flight & Start:** Conduct normal preflight & startup procedures
**Taxi:** 1500 ft
**Take off:** Normal takeoff procedures

**Climb:** $V_X$ to 50 ft AGL or clear of obstacles then $V_Y$ to 1000 ft AGL then climb to at least 2,500 ft MSL at no slower than 500 fpm

**Cruise:** Cruise at no lower than 2,500 ft MSL as desired (assuring sufficient energy for safe landing plus reserve energy)

**Arrival:** Descent to 1,000 ft AGL before entering 45° mid-field downwind leg of a conventional traffic pattern

**Landing:** Fly conventional downwind leg at 1000 ft AGL until abeam landing point and begin descending fly conventional based and turn final and land.

**Taxi:** 1,500 ft to parking spot

**Park & Shutdown:** Conduct normal parking and shutdown procedures

**Reserve:** 30 minutes reserve at cruise power (based on speed & altitude used for cruise above) remaining at end of flight

*Notes on Measured Parameters:*

***Cruise Time:*** *Time at or above 2,500 ft MSL*

***Cruise speed:*** *Average true airspeed during cruise at or above 2,500 ft MSL*

***Trip Distance:*** *Trip distance is measured between the centers of the A-B airport pair*

***Flight Time:*** *Time measured from takeoff to landing*

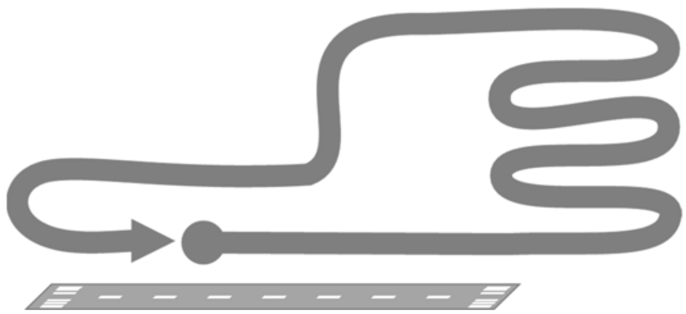
***Refuel Time:*** *Time to refuel or recharge with sufficient energy to repeat this flight*

***Total Energy:*** *Total energy used from pre-flight check to shutdown*

***Total Payload:*** *Total useful load less stored energy weight (batteries, liquid fuel, etc.)*

## 2.2 Local Training Flight (A to A Flight)

The local training flight scenario is intended to simulate a flight from a non-towered airport into a practice area for a duration of flight training and a return to the same airport. The total energy required for the trip includes normal pre-flight, taxi, takeoff, climb, training, descent, landing, normal shutdown and reserve energy. When following the standard for a local training trip as detailed below, the training maneuver time, training flight time, and/or refuel (recharge) time are variables that can be measured and provided.



Training Time: xxxxx (min.) Flight Time: xxxxx (min.)
Refuel Time: xxxxx (min.) Total Energy: xxxxx (KWh)
Total Payload: xxxxxx (lbs.)

**Airport Altitude:** Sea Level (0 ft)
**Conditions:** ISA / no wind
**Runway:** Hard smooth surface
**Pre-Flight & Start:** Conduct normal preflight & startup procedures
**Taxi:** 1500 ft
**Take off:** Normal takeoff procedures
**Climb:** $V_X$ to 50 ft AGL or clear of obstacles then $V_Y$ to 1000 ft AGL then climb to at least 1,500 ft MSL at no slower than 500 fpm
**Training Maneuvers:**

- Execute level 360° turn
- Climb 500 ft to 2000 ft MSL
- Execute level 360° turn
- Descend 500 ft to 1500 ft MSL
- Continue with training maneuvers as long as desired (assuring sufficient energy for safe landing plus reserve energy)

**Arrival:** Descent to 1,000 ft AGL before entering 45° mid-field downwind leg of a conventional traffic pattern
**Landing:** Fly conventional downwind leg at 1000 ft AGL until abeam landing point and begin descending fly conventional based and turn final and land.
**Taxi:** 1,500 ft to parking spot
**Park & Shutdown:** Conduct normal parking and shutdown procedures
**Reserve:** 30 minutes reserve at cruise power (based on speed & altitude used for training above) remaining at end of flight

*Notes on Measured Parameters:*
*Training Time: Time measured from start of first 360° turn to end of last training maneuver*
*Flight Time: Time measured from takeoff to landing*
*Refuel Time: Time to refuel or recharge with sufficient energy to repeat this flight*
*Total Energy: Total energy used from pre-flight check to shutdown*
*Total Payload: Total useful load less stored energy weight (batteries, liquid fuel, etc.)*

## 2.3 Traffic Pattern Flight

The traffic pattern flight scenario is intended to simulate traditional traffic pattern training work at a non-towered airport. The total energy required for the trip includes pre-flight, taxi, takeoff, completing the pattern, landing, normal shutdown and reserve energy. When following the standard for a traffic pattern, as detailed below, the number of traffic patterns, training time, and/or refuel (recharge) time are variables that can be measured and provided.

Number of Patterns: xxxxxx Flight Time: xxxxx (min.)
Refuel Time: xxxxx (min.) Total Energy: xxxxx (KWh)
Total Payload: xxxxxx (lbs.)

**Airport Altitude:** Sea Level (0 ft)
**Conditions:** ISA / no wind
**Runway:** Hard smooth surface no shorter than 2,500 ft
**Pre-Flight & Start:** Conduct normal preflight & startup procedures
**Taxi:** 1500 ft
**Take off:** Normal takeoff procedures
**Climb:** Runway heading at $V_X$ to 50 ft AGL or clear of obstacles then runway heading at $V_Y$ to 500 ft AGL at no slower than 500 fpm, it is permissible to turn crosswind and downwind during the climb once above 500 ft AGL to a pattern altitude of 1000 ft AGL
**Traffic Pattern:**

- Runway track at $V_X$ to 50 ft AGL then $V_Y$ to 500 ft AGL
- Turn to crosswind while climbing to at least 1000 ft AGL
- Turn to downwind and maintain 1000 ft AGL until abeam landing point
- Fly conventional base and final legs and touchdown at no faster than $V_{SO}$
- Execute a rolling take off again or taxi to parking
- Continue with training maneuvers as desired (assuring sufficient energy for safe landing plus reserve energy)

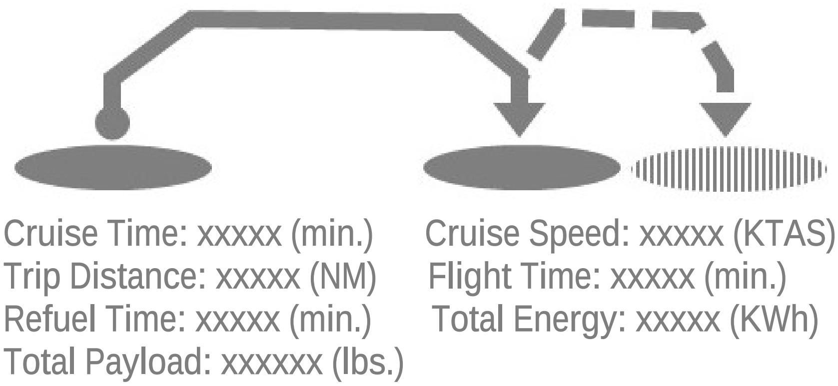
**Landing:** Fly conventional downwind leg at 1000 ft AGL until abeam landing point and begin descending fly conventional based and turn final and land.
**Taxi:** 1,500 ft to parking spot
**Park & Shutdown:** Conduct normal parking and shutdown procedures
**Reserve:** 30 minutes reserve at cruise power (based on speed & altitude used for downwind legs above) remaining at end of flight

*Notes on Measured Parameters:*
*Number of Traffic Patterns: Number of complete circuits of the traffic pattern*
*Flight Time: Time measured from first takeoff to last landing*

*Refuel Time:* *Time to refuel or recharge with sufficient energy to repeat this flight*
*Total Energy:* *Total energy used from pre-flight check to shutdown*
*Total Payload:* *Total useful load less stored energy weight (batteries, liquid fuel, etc.)*

## 2.4 Vertical Flight (A to B)

Vertical flight simulates a transportation activity between two off airport locations (such as heli-pads). The total energy required for the trip includes normal preflight including checks, liftoff, climb, cruise, descent, balked landing, balked climb, transition to an alternate, 2nd landing, normal shutdown and any remaining reserve energy. When following the standard for a vertical flight as detailed below, the cruise time, cruise speed, trip distance between pads, flight time, refuel (recharge) time, total energy used and/or total payload are variables that can be measured and provided.




**Airport Altitude (departure and destination):** Sea Level (0 ft)
**Conditions:** ISA / no wind
**Takeoff and Landing Site:** Hard smooth surface
**Pre-Flight & Start:** Conduct normal preflight & startup procedures
**Liftoff:** Conduct takeoff and climb to 50' AGL at no less than a 45° angle
**Climb:** 500 fpm or best rate to 1,000 ft MSL or above
**Cruise:** Cruise at no lower than 1,000 ft MSL as desired (assuring sufficient energy for safe landing plus reserve energy)
**Arrival:** Descent to 100 ft AGL directly above landing site
**Landing:** Conduct standard landing to ground contact
**Balk:** Balked landing takeoff and climb to at least 100 ft AGL
**Alternate:** Transition 2 NM to 2nd landing site
**Landing:** Conduct standard landing to ground contact
**Park & Shutdown:** Conduct normal parking and shutdown procedures
**Reserve:** State any additional range beyond balked to alternate conducted above.

*Notes on Measured Parameters:*
***Cruise Time:*** *Time at or above 1,000 ft MSL*
***Cruise speed:*** *Average true airspeed during cruise at or above 1,000 ft MSL*
***Trip Distance:*** *Trip distance is measured between the centers of the A-B landing site pair*
***Flight Time:*** *Time measured from takeoff to first landing*
***Refuel Time:*** *Time to refuel or recharge with sufficient energy to repeat this flight*
***Total Energy:*** *Total energy used from pre-flight check to shutdown*
***Total Payload:*** *Total useful load less stored energy weight (batteries, liquid fuel, etc.)*

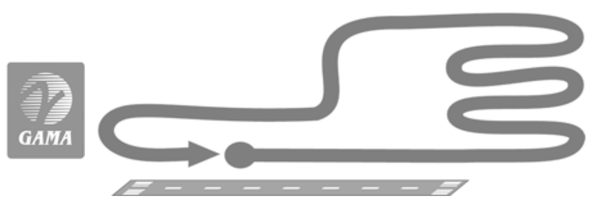
# 3.0 Illustrating Performance

Manufacturers who wish to indicate they have utilized this standard as a widely accepted practice for measuring performance may indicate the aircraft is capable of xxxxxxxxxxxxx (statement from standard measurement above) per the GAMA Hybrid & Electric Aircraft Performance Measurement. Manufacturers who have demonstrated compliance to this standard may also choose to illustrate performance using any of the following graphics. It is not necessary to list all measurement information when illustrating certain measurements. Slight modifications to the below graphics are acceptable to best fit with a particular use but the GAMA logo should not be modified.

## 3.1 Destination Trip (A to B Transportation)

Cruise Time: xxxxx (min.) Cruise Speed: xxxxx (KTAS)
Trip Distance: xxxxx (NM) Flight Time: xxxxx (min.)
Refuel Time: xxxxx (min.) Total Energy: xxxxx (KWh)
Total Payload: xxxxxx (lbs.)

## 3.2 Local Training Flight (A to A Flight)



Training Time: xxxxx (min.) Flight Time: xxxxx (min.)
Refuel Time: xxxxx (min.) Total Energy: xxxxx (KWh)
Total Payload: xxxxxx (lbs.)

## 3.3 Traffic Pattern Flight

Number of Patterns: xxxxxx Flight Time: xxxxx (min.)
Refuel Time: xxxxx (min.) Total Energy: xxxxx (KWh)
Total Payload: xxxxxx (lbs.)

## 3.4 Vertical Flight (A to B)


Cruise Time: xxxxx (min.)
Trip Distance: xxxxx (NM)
Refuel Time: xxxxx (min.)
Total Payload: xxxxxx (lbs.)

Cruise Speed: xxxxx (KTAS)
Flight Time: xxxxx (min.)
Total Energy: xxxxx (KWh)