THE

AIR FORCE PRIZE

A GROUNDBREAKING COMPETITION DRIVING TURBINE ENGINE DEVELOPMENT

OFFICIAL RULES

WWW.AIRFORCEPRIZE.COM

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IN THIS PACKET

WHAT'S THE PURPOSE?

To encourage innovation that supports the needs of the Air Force, a $2M prize is being established for the development of a turboshaft engine that can meet certain performance criteria. While it is possible that a device other than a turboshaft engine might meet some or all of these criteria, only turboshaft engines will satisfy the intent of this Prize because of their inherent long life and reliability. A successful engine must demonstrate the following:

WHILE OPERATING ON STANDARD JET A FUEL ...
Complete two run profiles on an Air Force engine test stand

IN THE 100 bhp (74.57 kW) CLASS ...
50 bhp < max continuous output < 150 bhp (37.3 kW < max continuous output < 112 kW)

WITH A POWER-TO-WEIGHT RATIO ≥ 2.0 bhp/lb$_{\text{(wet installed weight)}}$ (3.3 kW/kg$_{\text{(wet installed weight)}}$)

DEMONSTRATE AN AVERAGE BRAKE-SPECIFIC FUEL CONSUMPTION (BSFC) OF
0.55 lbm$_{\text{fuel}}$/bhp-hr (0.33kg$_{\text{fuel}}$/kW-hr) or lower during two 6-hour Air Force test profiles consisting of mission representative power settings.

Corrections will be applied to compensate for variability in ambient conditions during testing.

NOTE: *The official test procedures and Prize criteria will include additional details and clarification of Prize requirements and how those performance standards will be measured.*

BACKGROUND

INTENT OF PRIZE

Currently, piston engines and turboshaft engines are the common power plants used in aviation, ground vehicles, and power generation. For Air Force aviation needs in the 100 bhp class, piston engines have the advantage of fuel efficiency but the disadvantage of being heavy and requiring frequent overhauls; turboshaft engines have the advantage of low weight and longer periods between overhauls but are not as fuel efficient.

In balancing the needs for a variety of Air Force requirements, it would be desirable to have a power plant that:

- is efficient over a range of power output settings similar to a piston engine
- has a power density more like a turboshaft engine
- operates many thousands of hours between overhauls like a turboshaft engine
- uses a logistically available battlefield fuel such as Jet A
  (The use of Jet A would eliminate the entire aviation gas logistical requirement.)

In light of recent innovations in materials, design tools, manufacturing technologies, etc., it is a good time to explore the possibilities. Many of these technologies are scattered across industries large and small. Opening up the requirement to a wide audience is one way to find out what new ideas or approaches are available.

Meeting the Prize criteria means demonstrating 2x the fuel efficiency of today's small turbines and 3x the power-to-weight of a typical aviation piston engine, all in a turbine package that holds the promise of longevity and durability. This combination should be very competitive with current engines of all types.

SUMMARY

KEY ASPECTS OF THE CONTEST

REGISTRATION

Teams can register for this competition as soon as they decide to participate. The value of early registration lies in an Air Force review of a team's basic concept to determine whether the approach meets the intent of the contest. It is the goal of the Air Force to use this review to provide teams with feedback early in the process, before the team expends too many resources designing and building hardware in pursuit of this Prize.

See rules in Attachment A related to team registration.

VERIFYING ENGINE PERFORMANCE

Only a registered team can request that the Air Force test its engine to verify that it meets Prize parameters. A team must allow 30 days after Air Force receipt of its registration before being eligible to submit a request for verification testing in an Air Force test facility. One of the key requirements for requesting verification testing will be test data showing that the engine can reasonably be expected to meet the Prize criteria.

See rules in Attachment A related to requesting verification testing.

WINNING THE PRIZE

The first eligible team that provides an engine meeting all Prize criteria will be declared the winner. The Air Force will transfer the Prize money to the account specified by the team leader named in the registration. All tax liabilities are the responsibility of the winning team.

CALENDAR / MILESTONES

14 JAN 15	SECAF ANNOUNCEMENT AT ATLANTIC COUNCIL
24–25 MAR 15	FIRST "DISCOVERY MEETING" IN DAYTON, OH
15–16 APR 15	SECOND "DISCOVERY MEETING" IN LOS ANGELES, CA

DISCOVERY MEETINGS

Information and feedback sessions to help your team gather and understand the vital information for the Prize. This provides a unique opportunity to discuss potential concepts, questions, and suggestions with Air Force engineers and advisors.
FOR MORE INFORMATION VISIT AIRFORCEPRIZE.COM

MAY 15	ANNOUNCE RULES & OPEN CONTESTANT REGISTRATION
30 SEPT 18	LEGAL AUTHORITY TO AWARD AIR FORCE PRIZE EXPIRES

PRIZE AUTHORITY

National Defense Authorization Act (NDAA) authorizes the agencies of the Department of Defense to award prizes to spur innovation, solve tough problems, and advance core missions. The Air Force has chosen to use this authority to award a prize for the first entrant that meets the Prize criteria for a small, lightweight, fuel-efficient turbine engine. This program is being administered by the Air Force Research Laboratory (AFRL), which the Air Force has assigned sole responsibility for executing this Prize program.

Nothing contained herein shall be construed to obligate the Air Force or AFRL to any expenditure or obligation of funds in excess or in advance of appropriations in violation of the Anti-Deficiency Act, 31 U.S.C. Section 1341.

AIR FORCE REVIEW

The Air Force will establish a committee to review data and manage verification testing of entries to determine on a pass/fail basis whether engine performance successfully meets the Prize criteria. The committee will also review all team eligibility qualifications. The committee will comprise individuals with a collective knowledge of turbine engine design and performance, aviation and ground systems power plant requirements, and manufacturing processes. Committee members will have no interest in any entrant's submission and will be barred from materially participating in any entrant's efforts to win this Prize.

Government employees are under an obligation to protect proprietary information and/or trade secrets associated with all entries as required by 5 U.S.C. § 552(b)(4), Freedom of Information Act; Executive Order 12600, Predisclosure Notification Procedures for Confidential Commercial Information; 18 U.S.C. § 1905, Trade Secrets Act; 18 U.S.C. § 1831 et esq.; Economic Espionage Act; 35 U.S.C. § 205, Confidentiality for Inventions made by or for Federal Government; President's Patent Policy Memorandum of February 18, 1983; Air Force Instruction 51-303, para. 12, Information Marked as Proprietary and Non-Disclosure Agreements; and, any other statute, regulation, or requirement applicable to Government employees. The review committee may include Government contractors, who are also under an obligation to protect proprietary information and/or trade secrets as part of their contract. Establishment of any additional non-disclosure agreements between Government contractor committee members and registered teams will be the responsibility of the registered team.

CONTENTS

ATTACHMENT A

RULE MODIFICATIONS

UPDATES & QUESTIONS

The Air Force may release additional documents with rule updates, procedures, and other information as needed. These additional documents carry the full authority of the rules in this document.

This version of the rules is subject to change and may be superseded by later versions. The Air Force Review Committee has the authority to modify and interpret the rules at any time. The Air Force will communicate any modifications to the rules with a statement on the Air Force Prize website, and will email notifications of rule updates to registered participants.

Requests for rule clarifications, questions about proprietary or sensitive matters, and questions about the competition in general should be sent to info@airforceprize.com.

For questions regarding a specific system, the Air Force will protect proprietary information and respond only to the requester. In the case of questions related to rule clarifications, logistics of the contest, or other aspects of the contest that would apply to all contestants, the Air Force will post responses on the Air Force Prize website (www.airforceprize.com) to give all teams equal access to new information.

Decisions by the Air Force Review Committee are final.

ELIGIBILITY

Only registered teams are eligible to win the Prize.

All members of registered teams must be US persons 18 years of age or older.

> In the context of these rules, the term “US person” means any United States citizen or lawful permanent resident of the United States.

US persons, US corporate entities, and US academic entities are all eligible to register.

Federal entities and federal employees acting within the scope of their employment are not eligible to register or compete.

Federal employees acting outside the scope of their employment should consult their ethics official and appropriate management before attempting to register.

> Eligibility will be determined by the Air Force Review Committee on a case-by-case basis.

Each team member’s status as a US person will be verified by the Air Force when the team requests verification testing. At that time, all team members who are US citizens will be required to provide their full name, birthdate, and tax ID number; any team members who are US persons but not US citizens will be required to provide their full name, birthdate, and a copy of both sides of their Green Card.

> If a team meets all of the performance criteria for the Prize, but the status of any team member cannot be verified, the entire team may be disqualified.

Air Force personnel and support contractors who are executing this Prize program are not eligible to win the Prize, and are prohibited from materially participating in any entrant’s efforts to win this Prize.

No employees of the following companies are allowed to participate with or support any team’s effort to win this Prize: Innovative Scientific Solutions Inc., and Real Art.

REGISTRATION

A team leader must be identified.

> All official communication (e.g. rules, status, etc.) will be directed to the team leader.

Team leadership can be updated by submitting a change to the Air Force.

Team membership can be updated by submitting name additions/deletions/corrections to the Air Force.

Team name can be updated by submitting the change to the Air Force.

Inappropriate team names will not be accepted.

The engine concept described in the registration must meet the intent of the contest.

> If the Air Force deems that the concept described in the registration is not a turbine engine, or does not meet the intent of the contest in some way, registration will be denied and the Air Force will notify the team leader to discuss the concerns.

The team's engine concept can be updated by submitting changes to the Air Force; if the changes are such that the concept no longer complies with the intent of the contest, the Air Force will notify the team leader within 10 business days to discuss the concerns.

> The team will remain eligible to submit a request for verification testing based on a previously accepted concept description, but will not be allowed to submit a request based on the proposed updated concept description until the Air Force accepts the updated concept description.

Only one registration per team: registering multiple times could result in disqualification of all related registrations.

Only one registration per set of hardware: registering multiple times could result in disqualification of all related registrations.

Any apparent manipulation or distortion of the registration process through misleading, deceptive, or multiple registrations of people, teams, or hardware could result in disqualification of all registrations involved.

Registered teams agree to be identified publicly by their team name and team leader. They may choose, but are not required, to allow additional information about the team to be publicly released by the Air Force for publicity purposes.

Registered teams agree to provide a publicly releasable description of their approach; this description can be as general or as specific as the team deems appropriate.

> The intent is to use such descriptions to generate interest in the team and the contest without exposing any ideas that might be considered proprietary or sensitive in nature. It's recommended that the team include an external sketch or photo of the engine, if it can be done without exposing any sensitive information.
>
> If desired, and if space permits, supporting information such as pictures, links to other websites, and similar material can be included.

NOTE: *General instructions can be found in Attachment B. The Air Force Prize website will have an area for team registration.*

ENGINE WEIGHT

Engine weight will be based on a completely installed, wet engine, as configured for Air Force verification testing. Everything required for operation, except as specifically exempted here, counts toward engine weight. In all cases, the Air Force is the final authority on this determination.

All fluids and lubricants, other than the fuel, that are required for operation during verification testing will be included in the engine weight. For example, if an engine draws coolant or lubricant from a reservoir during verification testing, the weight of the fluid drawn from the reservoir will be added to the weight of the engine when calculating the total installed weight.

The frame used to adapt the engine to the Air Force test facility structure does not count as engine weight. If a piece of structure is required for engine operation then it must be included in engine weight.

Ducting added by the Air Force to route air, exhaust, etc., will not count toward engine weight.

The point at which the facility fuel supply connects to the engine, or any other contestant-supplied hardware/accessory, is the dividing point for purposes of engine weight. Everything on the engine side of the connection point, such as fuel pump, control hardware, lines, fittings, etc., is counted toward engine weight; everything on the facility side, such as fittings, line, facility control valves, and facility sensors, does not count toward engine weight. The connection point will be determined such that all contestant-required hardware, sensors, and actuators must be on the engine side of the connection point.

Connection points (example: for facility-supplied start power) are considered part of the engine weight; the wires, piping, or ducting leading to those connect points are not part of engine weight.
See Attachments D & E for further information on engine/facility interface requirements.

The first break point in the output shaft after it leaves the engine is the dividing point for purposes of determining engine weight. As with the fuel system, everything on the engine side of the connection point is counted toward engine weight; everything on the facility side, such as fittings, facility sensors, shaft extensions, and adaptors for connecting the engine to the facility test hardware does not count toward engine weight. The connection point will be determined such that all contestant-required hardware, sensors, and actuators are on the engine side of the connection point.
See Attachments D & E for further information on engine/facility interface requirements.

In the case of a contestant supplied gearbox that is separate from the engine and used only to change the rpm of the output shaft so it becomes compatible with the Air Force test hardware, the gearbox is considered to be part of the facility equipment as opposed to being part of the engine. Similarly, if the Air Force determines that an engine and gearbox assembly can be separated such that the engine can be started, run, and weighed without the gearbox attached, then the gearbox can be considered an adaptor that is part of the facility equipment as opposed to being part of the engine.

It may be possible to exempt sensors that are desired for safety or testing reasons but are not used in any way to control normal engine operation. For example, a sensor installed for the sole purpose of detecting actual or impending engine damage can be excluded from engine weight if the Air Force determines that it is not part of the control system for normal operation and it can be temporarily removed from the engine while the engine weight is being determined.

Control electronics that are separate from the engine will not count as part of the engine weight.

Only control signals can cross the boundary between the control electronics and the engine.

Everything on the engine side of the connection for control signals will count as engine weight and everything on the facility side of the connection for control signals does not count toward engine weight. The connection point will be determined such that all contestant-required hardware, sensors, and actuators other than the control electronics are on the engine side of the connection point.
See Attachments D & E for further information on engine/facility interface requirements.

ENGINE ELECTRICAL POWER

Control electronics that are separate from the engine and on the facility side of the connection for control signals may be powered using facility power.

> No facility power may be supplied to a physical effector that could potentially add energy to the shaft output of the engine.

If electrical power is needed for pumps, blowers, or other components required by the engine for normal operation, it must be supplied by the engine. Air at ambient temperature and pressure will be provided by the facility to blow at or over test hardware for cooling; the intent is to provide air similar to what might be available from a small inlet scoop on an aircraft.

See Attachment D for AC/DC voltages and phases available from facility, and for information regarding air available for directing at or over engine during verification testing.

ENGINE START

The engine must be able to start and run using only the hardware included in the wet installed weight, given electrical power or pressurized air. Contestants will be required to demonstrate an engine start without an applied load (analogous to starting on an aircraft). Once the load is attached, it will be determined whether the engine can be started with its built-in start capability or if some sort of assist will be required. Electrical power and compressed air for engine start will be available from the facility. In all cases, start power will be turned off after engine starts and before the beginning of performance verification testing.

It may be possible for the Air Force test facility to apply torque to the power output shaft of the engine to spin the engine as an assist with starting when the engine is attached to the verification testing load. If you anticipate the need for such a capability, provide the Air Force with an estimate of the engine's maximum shaft speed and the shaft speed required to start the engine. Depending on engine design and start requirements, this approach may not be an option for some engines. The Air Force will review the engine requirements and facility options and render a decision as to whether the option can be made available for verification testing of the engine.

For all verification testing, the engine must be started using only Jet A as a fuel. No alternate fuels, additional fuels, or additives can be used to assist with engine start during verification testing.

See Attachment D for available AC/DC voltages and phases available from facility for engine start. A compressed air system is available in the Air Force test facility.

TEST PROFILES

TO DETERMINE IF THE ENGINE WINS THE PRIZE

All verification testing must be conducted with Air Force-provided standard Jet A fuel.

Corrections will be applied to performance data to compensate for variability in ambient conditions during validation testing.

The official evaluation of the engine for award of the Prize will include one engine start without an applied load (previous section) and two test profiles (below).

TEST PROFILE 1 OF 2

Start the engine and bring it to its max continuous power setting.

Turn off or disconnect facility-provided start power.

SEGMENT 1: When contestant is ready, Air Force will begin 30 continuous minutes of data capture of fuel flow and power output while the engine operates at its max continuous power setting.

> As captured by a rolling average of 5 seconds or 10 points, whichever is greater, the engine must never output less than 70% of the average max continuous power demonstrated in this first segment of the profile. The use of a rolling average is intended to mitigate the risk that an intermittent sensor or control anomaly might result in lone data points lower than the threshold. If the engine cannot maintain the required output, then it does not meet the Segment 1 requirements. Therefore, the profile cannot be successfully completed and will not count toward the Prize.
>
> The engine must demonstrate an average power output (across this 30-minute segment) of greater than 50 bhp and less than 150 bhp (greater than 37.285 kW and less than 111.86 kW). If the engine cannot maintain the required output, then it does not meet the Segment 1 requirements. Therefore, the profile cannot be successfully completed and will not count toward the Prize.

Upon completion of the max continuous power segment, and without shutting down the engine, contestant will bring the engine to its 50% max continuous power operating point in preparation for the second test segment. The 50% target value will be determined from the actual, demonstrated average max power that was completed in Segment 1 of this test profile, and the contestant will have a maximum of 10 minutes from being told the target value until they must start the second test segment.

SEGMENT 2: When contestant is ready, or 10 minutes after contestant was told the target power setting for this segment, whichever comes first, the Air Force will begin 5 continuous hours of data capture of fuel flow and power output while the engine continues to operate at 50% of its max continuous power setting.

> As captured by a rolling average of 5 seconds or 10 points, whichever is greater, the engine must never output less than 35% of the average max continuous power demonstrated in Segment 1. The use of a rolling average is intended to mitigate the risk that an intermittent sensor or control anomaly might result in lone data points lower than the threshold. If the engine cannot maintain the required output, then it does not meet the Segment 2 requirements. Therefore, the profile cannot be successfully completed and will not count toward the Prize.
>
> The engine must be able to maintain an average power output (across this 5-hour segment) of no less than 40% and no greater than 60% of the average max power demonstrated in the first segment. If the engine cannot maintain the required output, then it does not meet the Segment 2 requirements. Therefore, the profile cannot be successfully completed and will not count toward the Prize.
>
> If the engine maintains an average power output (across this 5-hour segment) of more than 55% but not more than 60% of the average max continuous power demonstrated in Segment 1 of this profile, the profile will be considered successfully completed, but a penalty will be applied to the brake specific fuel consumption calculation. When calculating the brake specific fuel consumption of Segment 2, the average power output of the segment will be capped at 55% of the average continuous max power of the first segment. The measured fuel values will not be altered. The result will be the penalizing of the brake specific fuel consumption for Segment 2, and ultimately for the entire profile.

Upon completion of the 50% max continuous power segment, and without shutting down the engine, contestant will return the engine to its max continuous power operating point. The target value will be determined from the actual, demonstrated average max power that was completed in Segment 1 of this test profile, and the contestant will have a maximum of 10 minutes from being told the target value until they must start the third test segment.

SEGMENT 3: When contestant is ready, or 10 minutes after contestant was told the target power setting for this segment, whichever comes first, the Air Force will begin 30 continuous minutes of data capture of fuel flow and power output while the engine continues to operate at its max continuous power setting.

> As captured by a rolling average of 5 seconds or 10 points, whichever is greater, the engine must never output less than 70% of the average max continuous power demonstrated in the first segment of the profile. The use of a rolling average is intended to mitigate the risk that an intermittent sensor or control anomaly might result in lone data points lower than the threshold. If the engine cannot maintain the required output, then it does not meet the Segment 3 requirements. Therefore, the profile cannot be successfully completed and will not count toward the Prize.
>
> The engine must be able to maintain an average power output (across the entire 30-minute period) of at least 90% of the value demonstrated in the first segment of this profile. If the engine cannot maintain the required output, then it does not meet the Segment 3 requirements. Therefore, the profile cannot be successfully completed and will not count toward the Prize.

Upon completion of the third segment of the test, contestant will shut down the engine according to their standard operating procedures.

SEGMENT 4: The fourth segment of the profile begins upon engine shutdown and consists of a mandatory engine cool down.

> Upon engine shutdown, the engine must remain in a non-running, non-heated condition for at least 6 hours, with a reasonable expectation that the temperature of all components will approach the ambient temperature of the test facility. See Attachment D for information regarding expected ambient temperatures.

Test Profile 2 of 2

(same as first three segments of Profile 1 of 2)

Start the engine and bring it to its max continuous power setting.

SEGMENT 1: Same process and standards as Segment 1 of Profile 1 of 2.

Upon completion of the max continuous power segment, and without shutting down the engine, bring the engine to its 50% max continuous power operating point in preparation for the second test segment. (The 50% target value will be determined from the actual, demonstrated average max power that was completed in Segment 1 of this test profile.)

SEGMENT 2: Same process and standards as Segment 2 of Profile 1 of 2.

Upon completion of the 50% max continuous power segment, and without shutting down the engine, contestant will return the engine to its max continuous power operating point.

SEGMENT 3: Same process and standards as Segment 3 of Profile 1 of 2.

Upon completion of the third segment of the test, contestant will shut down the engine according to their standard operating procedures.

CORRECTIONS TO PERFORMANCE DATA

TO COMPENSATE FOR VARIABILITY IN AMBIENT CONDITIONS

Verification testing of the contestant's engine will be conducted by the Air Force at Wright-Patterson Air Force Base in Dayton, OH. The test cell will be inside a building and thus sheltered from inclement weather. Engine inlet air will be ducted into the cell from outside the building without any temperature or humidity conditioning. It can be expected that the engine will ingest air at temperature, pressure, and humidity conditions similar to the weather conditions around Wright-Patterson at the time of testing. Similarly, engine exhaust will be ducted from the cell to outside the building such that the engine exhaust can be expected to see local ambient pressures. The test area at Wright-Patterson AFB is approximately 800ft above sea level, with a typical ambient pressure of 14.3psia.

To compensate for the influence of pressure and temperature variations, engine output power and fuel consumption will be corrected to standard conditions. The correction factor shown here is for open-loop Brayton cycle engines. Engines operating under a different thermodynamic cycle will be subject to a cycle-specific correction factor with the intent of normalizing test results to standard sea-level conditions.

CORRECTED POWER =
$(P_{standard}/P_{ambient}) * (\text{Measured Power}) / (1 + 0.0126 * (T_{standard} - T_{ambient}))$

CORRECTED FUEL USE =
$(P_{standard}/P_{ambient}) * (T_{standard}/T_{ambient}) * (\text{Measured Fuel Use}) / (1 + 0.0126 * (T_{standard} - T_{ambient}))$

WHERE
$P_{standard}$ = 101.325kPa or 14.696psia [equation requires absolute pressure]
$T_{standard}$ = 288.15K [equation requires temperature in Kelvin]

The corrected power output of the engine will be divided by the weight of the engine to determine the expected Specific Power at standard conditions for Prize purposes.

The corrected fuel consumption will be divided by the corrected power to determine the Brake Specific Fuel Consumption at standard conditions for Prize purposes.

FLOW CHART

DETERMINATION OF SPECIFIC POWER AND BRAKE FUEL CONSUMPTION

(This flow chart is intended as a guide. It is not a replacement for, or a change to, any written rules. If there is a conflict with a written rule, the written rule will take precedence. Note that the equations shown in the flow chart for correcting test results to sea-level standard conditions are specific to open-loop Brayton cycle engines; if the engine being tested is not an open-loop Brayton cycle engine, a cycle-specific correction will be applied.)

BEGIN SEGMENT 1.

TARGET POWER = CHOSEN BY CONTESTANT

MONITOR INSTANTANEOUS & AVERAGE POWER.

WHERE SEGMENT 1 AVERAGE POWER IS:

$$POWER_{1avg} = \sum_{i=0}^{n} \frac{(shaft\ horsepower)_i * \Delta time_i\ [sec]}{Segment\ 1\ duration\ [sec]}$$

(As determined from Air Force collected data.)

CORRECT TO STANDARD CONDITIONS:

(open-loop Brayton correction shown—cycle-specific correction will be used)

$$POWER_{1avg\ corrected} = \sum_{i=0}^{n} \frac{(P_{standard}\,[psia]/P_{ambient\ i}\,[psia])*(shaft\ horsepower)_i * \Delta time_i\ [sec]}{(1+0.0126*(T_{standard}\,[K]-T_{ambient\ i}\,[K])) * Segment\ 1\ duration\ [sec]}$$

REQUIREMENTS FOR SUCCESSFUL COMPLETION OF SEGMENT 1:

AS CAPTURED BY A ROLLING AVERAGE OF 5 SECONDS, OR 10 POINTS, WHICHEVER IS GREATER, THE ENGINE MUST NEVER OUTPUT LESS THAN 0.7 * $POWER_{1avg\ corrected}$ DURING SEGMENT.

$POWER_{1avg\ corrected}$ *MUST BE GREATER THAN 50hp*

$POWER_{1avg\ corrected}$ *MUST BE LESS THAN 150hp*

DID ENGINE SUCCESSFULLY COMPLETE SEGMENT 1?

NO → PROFILE UNSUCCESSFUL; RE-ACCOMPLISH IF DESIRABLE AND IF TIME IS AVAILABLE.

YES

WITHOUT SHUTTING DOWN ENGINE, BEGIN SEGMENT 2.

$TARGET\ POWER = 0.5 * POWER_{1avg\ corrected}$

MONITOR INSTANTANEOUS & AVERAGE POWER.

WHERE SEGMENT 2 AVERAGE POWER IS:

$$POWER_{2avg} = \sum_{i=0}^{n} \frac{(shaft\ horsepower)_i * \Delta time_i\ [sec]}{Segment\ 2\ duration\ [sec]}$$

(As determined from Air Force collected data.)

CORRECT TO STANDARD CONDITIONS:

(open-loop Brayton correction shown—cycle-specific correction will be used)

$$POWER_{2avg\ corrected} = \sum_{i=0}^{n} \frac{(P_{standard}\ [psia]/P_{ambient\ i}\ [psia]) * (shaft\ horsepower)_i * \Delta time_i\ [sec]}{(1+0.0126*(T_{standard}\ [K]-T_{ambient\ i}\ [K])) * Segment\ 2\ duration\ [sec]}$$

REQUIREMENTS FOR SUCCESSFUL COMPLETION OF SEGMENT 2:

AS CAPTURED BY A ROLLING AVERAGE OF 5 SECONDS, OR 10 POINTS, WHICHEVER IS GREATER, THE ENGINE MUST NEVER OUTPUT LESS THAN $0.35 * POWER_{1avg\ corrected}$ DURING SEGMENT.

$POWER_{2avg\ corrected}$ *MUST BE NO LESS THAN* $0.40 * POWER_{1avg\ corrected}$

$POWER_{2avg\ corrected}$ *MUST BE NO GREATER THAN* $0.60 * POWER_{1avg\ corrected}$

DID ENGINE SUCCESSFULLY COMPLETE SEGMENT 2?

NO → PROFILE UNSUCCESSFUL; RE-ACCOMPLISH IF DESIRABLE AND IF TIME IS AVAILABLE.

YES

WITHOUT SHUTTING DOWN ENGINE,
BEGIN SEGMENT 3.

TARGET POWER = $POWER_{1avg\ corrected}$

MONITOR INSTANTANEOUS & AVERAGE POWER.

WHERE SEGMENT 3 AVERAGE POWER IS:

$$POWER_{3avg} = \sum_{i=0}^{n} \frac{(shaft\ horsepower)_i * \Delta time_i [sec]}{Segment\ 3\ duration\ [sec]}$$

(As determined from Air Force collected data.)

CORRECT TO STANDARD CONDITIONS:
(open-loop Brayton correction shown—cycle-specific correction will be used)

$$POWER_{3avg\ corrected} = \sum_{i=0}^{n} \frac{(P_{standard}[psia]/P_{ambient\ i}[psia])*(shaft\ horsepower)_i * \Delta time_i [sec]}{(1+0.0126*(T_{standard}[K]-T_{ambient\ i}[K])) * Segment\ 3\ duration\ [sec]}$$

REQUIREMENTS FOR SUCCESSFUL
COMPLETION OF SEGMENT 3:

AS CAPTURED BY A ROLLING AVERAGE OF
5 SECONDS, OR 10 POINTS, WHICHEVER IS GREATER,
THE ENGINE MUST NEVER OUTPUT LESS THAN
0.70 * $POWER_{1avg\ corrected}$ DURING SEGMENT.

$POWER_{2avg\ corrected}$ *MUST BE NO LESS THAN*
*0.90 **

DID ENGINE
SUCCESSFULLY COMPLETE
SEGMENT 3?

NO → PROFILE UNSUCCESSFUL;
RE-ACCOMPLISH
IF DESIRABLE AND
IF TIME IS AVAILABLE.

YES

IS THIS THE FIRST TIME THE
ENGINE HAS SUCCESSFULLY
COMPLETED ALL 3 SEGMENTS?

NO → PROFILE COMPLETED;
SHUT DOWN ENGINE;
PROCEED TO
CALCULATIONS.

YES

SHUT DOWN ENGINE; BEGIN SEGMENT 4.

TARGET POWER = 0

REQUIREMENTS FOR SUCCESSFUL COMPLETION OF SEGMENT 4:

ENGINE MUST REMAIN IN A NON-RUNNING, NON-HEATED CONDITION FOR AT LEAST 6 HOURS TO ALLOW THE TEMPERATURE OF ALL OF ITS COMPONENTS TO APPROACH THE AMBIENT TEMPERATURE OF THE TEST FACILITY.

DID ENGINE SUCCESSFULLY COMPLETE SEGMENT 4?

NO → PROFILE UNSUCCESSFUL; RE-ACCOMPLISH IF DESIRABLE AND IF TIME IS AVAILABLE.

YES

PROFILE COMPLETED; SHUT DOWN ENGINE; PROCEED TO CALCULATIONS.

CALCULATIONS

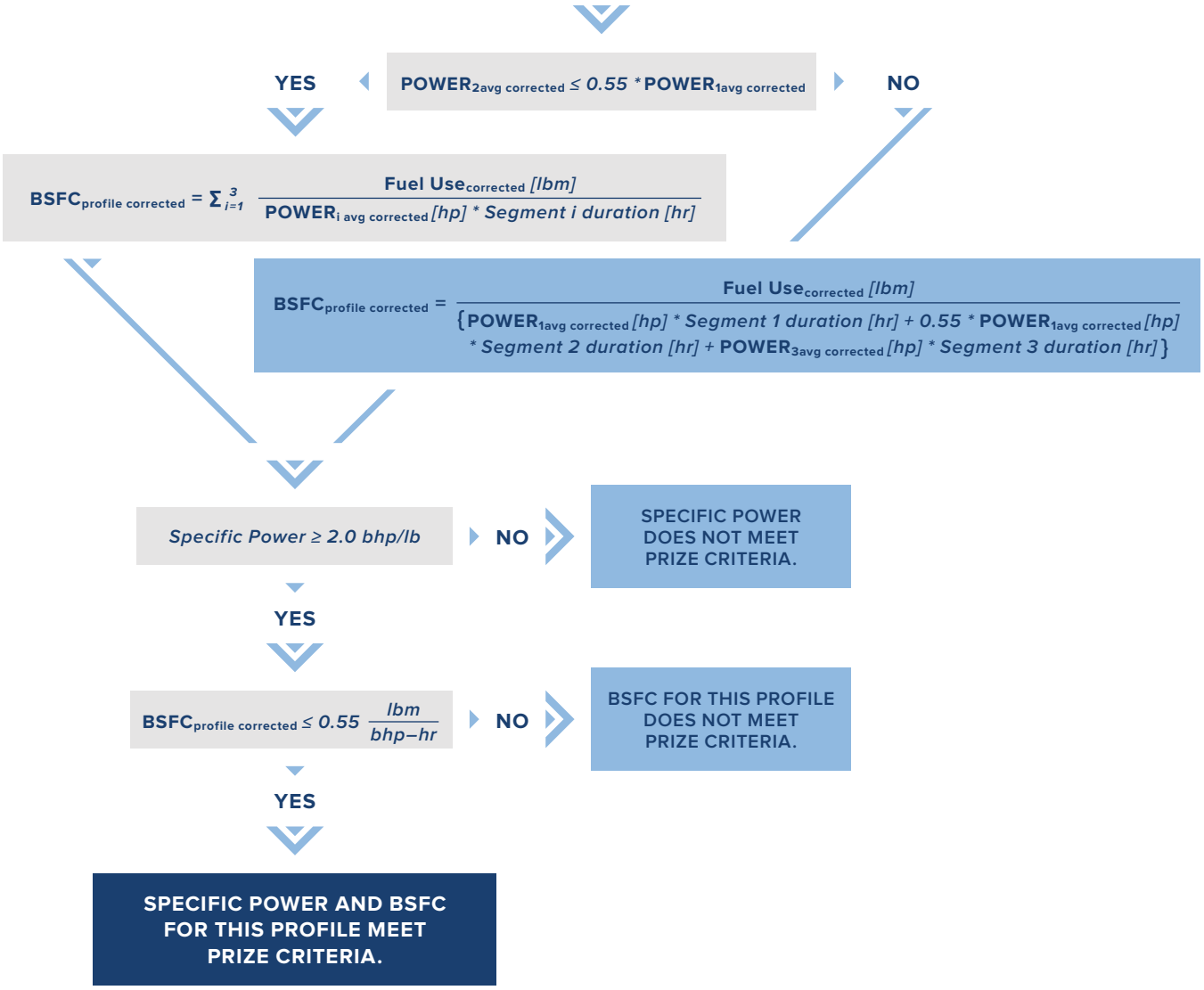
$$\text{Specific Power} = \frac{\text{POWER}_{1\text{avg corrected}}\,[hp]}{\text{Engine Weight}\,[lb]}$$

(Engine Weight as determined by Air Force; see rules concerning Engine Weight.)

CORRECT TO STANDARD CONDITIONS:

(open-loop Brayton correction shown—cycle-specific correction will be used)

$$\text{Fuel Use}_{\text{corrected}} = \sum_{i=0}^{n} \frac{(P_{\text{standard}}\,[psia]/P_{\text{ambient }i}\,[psia])*(T_{\text{standard}}\,[K]/T_{\text{ambient }i}\,[K])*(\text{Fuel Use}_i\,[lbm])}{(1+0.0126*(T_{\text{standard}}\,[K]-T_{\text{ambient }i}\,[K]))}$$


$POWER_{2avg\ corrected} \leq 0.55 * POWER_{1avg\ corrected}$
YES
NO
$BSFC_{profile\ corrected} = \sum_{i=1}^{3} \frac{Fuel\ Use_{corrected}\ [lbm]}{POWER_{i\ avg\ corrected}\ [hp] * Segment\ i\ duration\ [hr]}$
$BSFC_{profile\ corrected} = \frac{Fuel\ Use_{corrected}\ [lbm]}{\{POWER_{1avg\ corrected}\ [hp] * Segment\ 1\ duration\ [hr] + 0.55 * POWER_{1avg\ corrected}\ [hp] * Segment\ 2\ duration\ [hr] + POWER_{3avg\ corrected}\ [hp] * Segment\ 3\ duration\ [hr]\}}$
Specific Power ≥ 2.0 bhp/lb
NO
SPECIFIC POWER DOES NOT MEET PRIZE CRITERIA.
YES
$BSFC_{profile\ corrected} \leq 0.55\ \frac{lbm}{bhp-hr}$
NO
BSFC FOR THIS PROFILE DOES NOT MEET PRIZE CRITERIA.
YES
SPECIFIC POWER AND BSFC FOR THIS PROFILE MEET PRIZE CRITERIA.

MAKING A REQUEST
FOR VERIFICATION TESTING

Only a registered team can request verification testing.

Time and date of request submission will be recorded for all verification testing requests.

- Requests will be prioritized by time and date of receipt.
- In the event that multiple valid requests are received in a short period of time, it is the intent of the Air Force to execute testing in the order that the requests were received.

Must allow 30 days after Air Force receipt of registration before being eligible to submit a request for verification testing.

Must provide test data showing that the engine is expected to meet the Prize criteria.

- Contestant must test engine by completing the same two test profiles that will be used by the Air Force during verification testing.
- Must include fuel consumption, power output, and ambient condition data along with engine weight as part of request for verification testing.

Must include team member information needed for verification of US Person status.

Must be requesting verification testing for an engine that conforms to the concept described in the registration and to the intent of the contest.

Must include drawings, dimensions, interface specifications, etc. sufficient for determining whether the engine and related equipment are physically compatible with the Air Force test cell hardware.

- See Attachments D & E for engine mounting and interface information.

Must include sufficient operating procedures, protocols, or other information to support the argument that a reasonable effort has been made to prepare the engine, its controls, and related equipment for installation into the Air Force test facility for testing.

- See Attachments D & E for engine mounting and interface information.

Consistent with OSHA regulations, Material Safety Data Sheets (MSDSs) must be provided for all materials, fluids, lubricants, adhesives, sealants, etc. that may pose a health risk to personnel who will be testing the engine. When determining the potential for risk, it is important to consider a worst case scenario engine failure during which any part of the engine, internal or external, could become broken, scattered, aerosolized, melted, or burned.

Any effort to distort or manipulate the verification test requesting process through deceptive or multiple requests could result in cancellation of all involved requests.

TESTING RULES

Any engine submitted for demonstration/testing must meet the intent of the contest.

> If the Air Force deems that the engine submitted for demonstration/testing is not a turbine engine, or not consistent with the intent of the contest, the engine will be ineligible for the Prize and the Air Force will have no obligation to support testing.

Once the engine is installed and both the engine and the test facility have been checked for safety and deemed ready for engine start, the contestant will be given the go-ahead to start and run the engine for evaluation beginning on the morning of the next business day.

> The contestant will have up to 5 business days to complete the required test profiles.
>
> A test profile may not be started for score after 2 p.m. local time on any one of the 5 business days unless it is to facilitate Air Force support of the test.
>
> Access to the test facility will begin with the normal business day and last until the test profile ends, or for 12 hours, whichever occurs second.
>
> No access will be provided on non-business days.

Only data from a fully completed test profile will count toward the Prize.

If any changes are made to the engine, the next test profile will be considered the first profile for the “new” engine configuration.

Once a test profile has been completed, no part of the engine, its cooling system, or control hardware can be repaired or replaced except as specifically exempted here:

> Fluids and lubricants can be replaced with fresh fluids and lubricants having the same specifications.
>
> Externally mounted or attached fuel lines and/or fuel line connections can be repaired or replaced to prevent leakage but not to improve or alter performance.
>
> Externally mounted or attached wiring can be repaired or replaced to ensure functionality but not to alter functionality.
>
> Externally mounted or attached sensors can be repaired or replaced to ensure functionality but not to alter functionality.

If there is time to complete more than 2 test profiles during the 5 days, the contestant may elect to complete additional test profiles.

> As long as no part of the engine, its cooling hardware, or control hardware is repaired or replaced, all profiles successfully completed are eligible to count toward that engine configuration.

The Air Force will use the data from two successful profiles, of the contestant’s choosing, provided they are both attributable to a single engine configuration.

Time lost to delays caused by failure of the Air Force to provide reasonable test support will not be counted against the contestant; arrangements will be made to make sure the appropriate amount of test time is made available to the contestant for the demonstration/testing.

The Air Force reserves the right to shut down a test if it is determined that there is undue risk to either personnel or hardware.

> Test safety protocol will be specific to each installation, because risks may differ with each contestant’s design.
>
> At a minimum, the Air Force will install and control a master electrical shutoff and a master fuel cutoff for use in emergency situations.
>
> Risks will be evaluated and discussed before testing. Every effort will be made to allow the contestant to determine when and how to terminate or continue a test, but in the event of a quickly degrading situation, there may not be time for a collaborative discussion.

PREPARING FOR A TEST

IN THE AIR FORCE TEST FACILITY

Each team will be required to sign an agreement with the Air Force to accommodate testing on Air Force property. A copy of the model Agreement will be posted on the Air Force Prize website for review.

Air Force onsite contractor personnel will be assisting the government with verification testing. Information on which contractors will support the testing will become available as the test is being scheduled. It is the responsibility of contestants to establish non-disclosure agreements with these contractors as seems appropriate.

It is the responsibility of the contestant to prepare their engine for installation into the Air Force test facility.

It is the responsibility of the contestant to transport their engine, people, and any needed tools/hardware/supplies/etc. to and from the Air Force test facility.

Expect a half-day pretest review with the Air Force to discuss test hardware compatibility and readiness for installation into the Air Force test facility.

The Air Force will not provide engine mounting hardware beyond what is specified in Attachment D.

The Air Force will provide standard connectors, plugs, adaptors, and similar interface components as specified in Attachment D.

If the rotational speed of the engine's output shaft is compatible with the test hardware in the Air Force facility, all reasonable effort will be made to use the Air Force test hardware during the required validation testing profiles.

> If the Air Force determines that there is justifiable cause for the contestant to provide their own load, the Air Force will make the final determination regarding how to measure output rpm, torque, etc.
>
> If the contestant provides a gearbox or other adaptor between the engine and the Air Force test hardware, the Air Force will make the final determination regarding how to measure output rpm, torque, etc.

GENERAL TIMELINE EXPECTATIONS

RELATED TO TESTING

To facilitate test scheduling, expect approximately 6 weeks between requesting a verification test and the start of engine installation into a test facility.

Expect at least 2 weeks to install the engine in an Air Force test facility, especially if modifications are required.

Testing will require about 5 business days.

Removing hardware from the test cell shouldn't take more than a day or so.

National security and Air Force mission requirements take precedence over verification testing requests. The Air Force may be required to terminate, interrupt or delay verification testing whenever such termination, interruption or delay is in the best interests of the Government.

ATTACHMENT B

REGISTRATION

The Air Force Prize website will have an area for team registration. Use the contact form on the website to seek assistance if unable to register through the Air Force Prize website. See Attachment A for rules related to team registration.

When filling out the registration form, you will be asked to provide:

TEAM NAME

NAME AND CONTACT INFORMATION FOR TEAM LEADER

NAMES OF ALL TEAM MEMBERS

EACH TEAM MEMBER'S STATUS AS A US PERSON

BRIEF PUBLIC RELEASE DESCRIPTION OF TEAM AND APPROACH
The intent is to include this publicly releasable description along with the team name on the Air Force Prize website. This description can be as general or as specific as the team deems appropriate. Ideally, this description can generate interest in the team and the contest without exposing any ideas that might be considered proprietary or sensitive in nature.

DESCRIPTION OF THE TEAM'S CONCEPT FOR USE BY THE AIR FORCE TO EVALUATE WHETHER THE APPROACH MEETS THE INTENT OF THE CONTEST
This will not be released beyond the Air Force contest organizers

- Provide a description of your engine concept. How does it work; why do you think it can meet the prize criteria?
- Pictures, sketches, or calculations would be welcome.
- Provide an estimate of the minimum and maximum speed of the output shaft of your engine concept.

The intent is for the Air Force to be able to use this description to develop an understanding of what the team is trying to do. The Air Force will use this understanding to provide some quick feedback to the team as whether the Air Force thinks the plans are in line with the rules and intent of the contest. Early feedback can help the team avoid expending resources and time on something that doesn't meet contest rules; and early awareness of estimated design parameters can help the Air Force prepare appropriate test capabilities for future verification testing.

The Air Force contest organizers will respond within 10 business days with a determination on whether the approach meets the intent of the contest.

ATTACHMENT C

REQUEST FOR VERIFICATION TESTING

Must allow 30 days after Air Force receipt of registration before being eligible to submit a request for verification testing.

PROVIDE

Team Name

Name and contact information for Team Leader

Full name, birthdate, and tax ID number for all team members who are US citizens; and full name, birthdate, and a copy of both sides of Green Card for any team member who is a US person but not a US citizen.

Test data showing that the engine can reasonably be expected to meet the Prize criteria.
See rules in Attachment A related to requesting verification testing.

Basic engine parameters such as maximum power output, maximum exhaust temperature, airflow at expected power settings, and speed range of output shaft at expected power settings.

Evidence (such as applicable drawings, dimensions, interface specifications, etc.) to show that the engine, controls, and equipment are ready for installation into the Air Force test facility.
See rules in Attachment A related to requesting verification testing.

Consistent with OSHA regulations, Material Safety Data Sheets (MSDSs) must be provided for all materials, fluids, lubricants, adhesives, sealants, etc. that may pose a health risk to personnel who will be testing the engine. When determining the potential for risk, it is important to consider a worst case scenario engine failure during which any part of the engine, internal or external, could become broken, scattered, aerosolized, melted, or burned.

ATTACHMENT D

AIR FORCE TEST CAPABILITIES / REQUIREMENTS

PROVIDED BY AIR FORCE:

DRAWINGS, DIMENSIONS, AND APPLICABLE SPECIFICATIONS OF AIR FORCE TEST HARDWARE.
Base plate geometry and applicable fastener specifications…drawings in Attachment E
Dynamometer position and alignment relative to base plate…drawings in Attachment E

SPECIFICATIONS FOR DYNAMOMETER
Min/Max rotational speed and min/max torque or power limits–TBD
Shaft interface specifications/requirements–TBD

ELECTRICAL POWER OR COMPRESSED AIR FOR ENGINE START
120/240Vac single phase 60Hz, or 208/480Vac 3 phase 60Hz
12–48Vdc up to 100A
Air Force will have an emergency cutoff in the power system for use in an emergency
1 lbm/s at 100psi air (different mass flow/pressure potentially available upon request)

ELECTRICAL POWER FOR ENGINE CONTROLS
120/240Vac single phase 60Hz, or 208/480Vac 3 phase 60Hz
12–48Vdc up to 100A
Air Force may have an emergency cutoff in the lines if required for safety

FACILITY AIR AVAILABLE TO CONTESTANT FOR COOLING FLOW
1.35 lbm/s at a stagnation pressure consistent with 120 knot flow (up to 0.3psig)
Air temperature very near local ambient
(Intent is to provide airflow equivalent to that delivered by a 4″ round inlet on an aircraft traveling at an airspeed of 120 knots.)

FUEL
Standard Jet A
Provided at up to 50psig
Standard fittings, such as: SAE NPT fitting or SAE tubing with Swagelok fitting (male or female)
Air Force will have an emergency cutoff in the fuel supply line

TOOLS, SUPPLIES, ETC.*
Tool set … inventory in Attachment F
Various hand and parts cleaning supplies

SAFETY EQUIPMENT PROVIDED BY AIR FORCE
Personal safety equipment such as eye protection, hearing protection, and gloves
Test-area safety equipment to protect facility and personnel

SUPPORT STRUCTURE AND SHIMS TO ASSIST IN SUPPORTING AND ALIGNING ENGINE FOR TEST

AIR FORCE TECHNICAL SUPPORT WILL BE PRIMARILY FOCUSED ON FACILITY PREPAREDNESS AND SAFETY OVERSIGHT

****NOTE:** *Contestants are welcome to bring their own tools.*

PROVIDED BY CONTESTANT:

LISTING OF, AND MSDS FOR, ALL FUELS, COOLANTS, SOLVENTS, AND LUBRICANTS

LISTING OF, AND MSDS FOR, ALL ENGINE COMPONENTS OR EQUIPMENT THAT MIGHT BE TOXIC OR HAZARDOUS EITHER DURING INSTALLATION AND TEST, OR IN THE EVENT OF ENGINE FAILURE OR FIRE

POWER REQUIREMENTS

Voltage, amperage, frequency, and phase requirements for electric starting of engine, if applicable
Pressure, mass flow, and connection fitting specifications required for air starting of engine, if applicable
Torque and rpm required for spin starting of engine, if previously coordinated with and approved by the Air Force
Power requirements for any off-engine equipment

CONTROLS AND DATA CAPTURE SPECIFICATIONS AND REQUIREMENTS

FUEL FITTING SPECIFICATIONS

EXHAUST INTERFACE SPECIFICATIONS

Position and mechanical interface

ENGINE MOUNTING SPECIFICATIONS

Position
Dimensions
Mechanical Interface

ATTACHMENT E

DRAWINGS

NOT YET COMPLETED

ATTACHMENT F

TOOL SET INVENTORY

NOT YET COMPLETED

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