HPA Design Considerations:
A review on theoretical and experimental progress

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Abstract

Human powered aircraft (HPA) is a type of flayers that fly only by the Human Muscles power. The construction of this type has begun from the early days in 1950 and till now it has been under development and progress. The first production aims were only to have a beautiful entertainment but after that Henry Kramer began a new era for this aircraft by establishment of the Kramer prize for this type. This article aims to have a review on the design process, regarding to the energy concepts and drag limitations. Assessment on several configurations is included, as well as the discussion about the future of this type of airplane.

Keywords: Human Powered Aircraft (HPA), Biplane, wing-grid, CFRP

Introduction

Human powered aircraft (HPA) is a type of flayers that fly only by the Human Muscles power. From the early days in 1950 this type production began and till now the progress of this type is under development and construction. Henry Kramer Industrialist was one of those who played a strong role in developing of this type be establishment of significant Kramer prizes. The second hope for this kind is the bird man rallies in Japan. In these competitions every year there is …. Teams from many universities of Japan that trying to build and fly the best HPA.
There is still hope for this type to become more popular in society but it needs a bit more engineering design and novelty.
In HPA design the dominant priority is the Human muscles power. You can see the change of this power over time in figure one (from reference 1).
For a typical human the sustainable legs muscles power is 250 what (from reference 2).

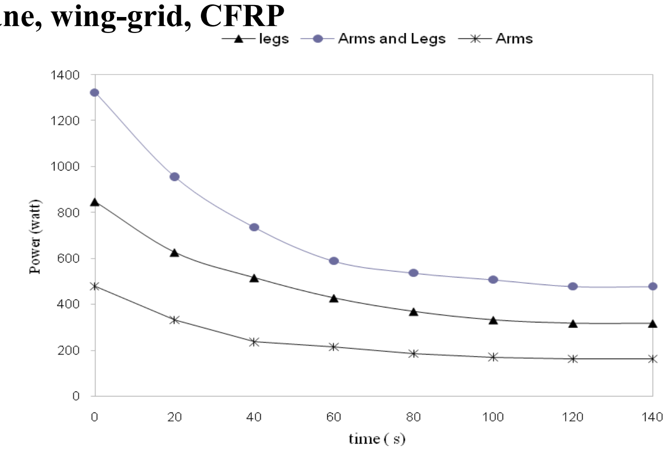


Chart 1. Energy Histogram for Human body

Main formulas and calculations required for the preliminary design process:

As in all aircraft's design we know this relation:

Formula 1 : Power Estimation $P = \dfrac{W}{L/D} \times V$

We must Reduce Weight and Increase L/D ratio to have opportunity to add velocity in constant power of 250 watt. For having less weight you should use smarter materials and structural weight reduction tricks such as biplane configuration. For higher Lift to Drag ratio you should add your aspect ratio and employ better airfoils and wing tip devices like winglets and wing grids. And after all you should Design for higher than stall speeds. These are all limitations for HPA Design. We will discuss about Statistics and ideas for overcoming theses limits below.

Ground Effect estimation :

This Formula from Reference 5 is a Ground effect formula Specialized for HPA Design Usage. For take off there is a critical need to auxiliary power as now this power bring to HPA from humans hands beyond HPA doors. But the key factor for take off without any outdoor help is Ground effect.

Formula 2 : Ground Effect Factor

$$G = \frac{33*(h/b)^{1.5}}{1+33*(h/b)^{1.5}}$$

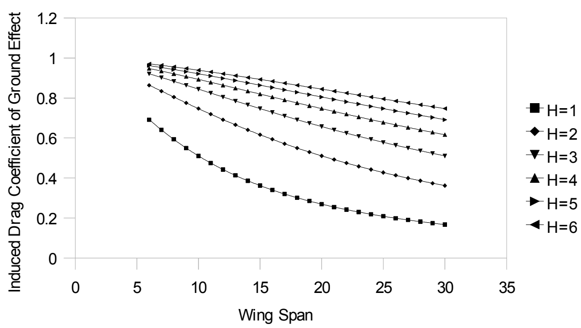


Chart 2. HPA Ground Effect Estimation

Lift , Drag and Control Analysis can easily be performed by use of QFLR5 Software (reference 7).

Statistics Charts

We gather a complete database of all HPA's Built up to these days in the world. But we don't consider data of many of Japanese's HPA's in this tables because many of this HPA's were built for birdman Competitions by students and they were in fact a new assembly of former ones without any new Idea and design approach. This chart was drawn for 66 HPA's till now built in the world.

Configuration Statistics

Except two Gossamers of Doctor Paul Mc. Cready the real father of HPA and some similar copies of Japanese Students all HPA's have tail and Boom. In new Designs after the RCFT (Rain forced Carbon Fiber Tube) Revolution in HPA Building almost all Booms were RCFT.
Here is a table of Configuration Selection for HPA's:

Configuration Feature	Number of HPA's
conventional	58
Canard	2
Biplane	2
Two tandem seat	2
Low Wing	1
Mid Wing	1

Table1. Number of HPA of Any Configuration

Tail Type	Number of HPA's
Conventional	35
T Tail	7
H tail	2
cruciform	10

Table 2. Tail Configuration for HPA's

chart 3. Wing Aspect ratio chart

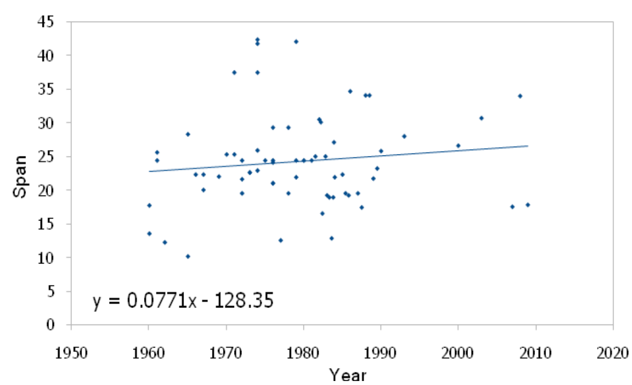


chart 4.Wing Span Chart

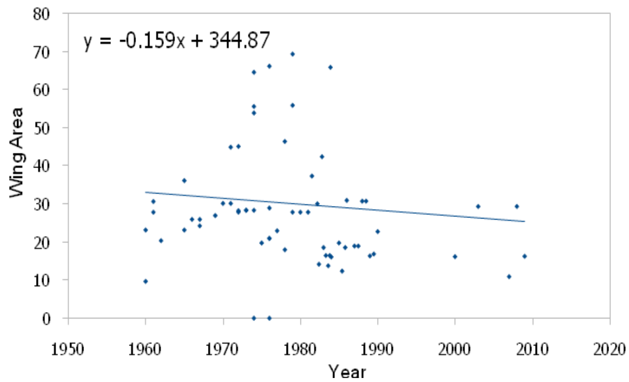


Chart 5.Wing area chart

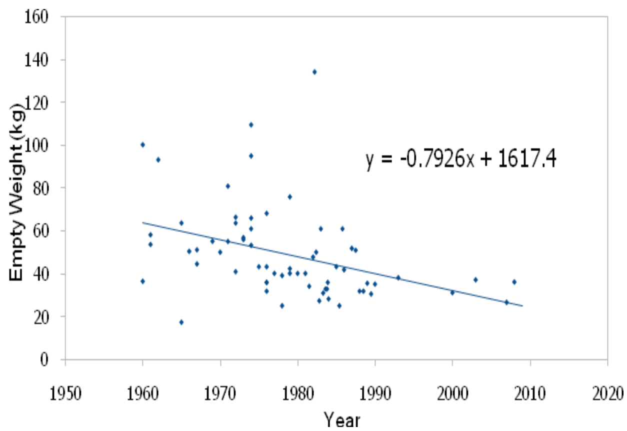


Chart 6. Empty weight chart

Design Considerations

Geometric Parameters:

Canard or tail:

Although Almost all HPA's has been Built in Tail configuration but the question is why Paul Mc. Cready Used Canard. First Idea is to prevent Inverse Lift by tail. In HPA Design your power is limited and upon this you should be so careful about anything needs extra power and having some inverse lift and for filling this reduction you should pay some more induced drag for extra lift by wing except tail drag. But in case of gossamers the wing and canard area is really so more than usual HPA's and this will bring us reduction in induced drag and extra skin friction drag. But canard has some more features that we will respect this selection by Paul Mc. Cready.

Take off with or without Ground effect:

Ground effect is a useful opportunity for HPA take-off because your power is so limited and you should use any decision for a better take off. Know many HPA's don't think about this because in Kramer and Bird man rally competitions' you can have people's help for takeoff.

One wing or biplane:

This is a really important decision but many of aircrafts want to face a simpler build and for there more they select on wing. But biplane can weigh less because of weaker materials in wing root for less bending moment.
it should be regarded that Biplane have its own problems too for example you have four wing tip and then for wing tip vortex.

Wing-grid or high aspect ratio:

Propulsion and Power Transmition Design Parameters:

Propulsion feature	Number of HPA's
Tail propeller	18
Nose Propeller	13
Pod Propeller	9
Pylon propeller	17
Two propeller	1

Table3. Propulsion unit Statistics

Pusher or puller (tractor) propeller:

The prop position is Important too. You will lose a bit of power for overcoming the perturbation by propeller on wing. And upon this you can see the number of nose propeller

HPA's in Table is about one fifth of all.
But for bringing back the propeller you will need a shaft and this will bring extra weight and this means needing extra power for your plane.

Pros & Cons Table of Configuration selection:

	Drag reduction	More Ground effect	Energy consumption	Less noise	Weight reduction
Biplane	×	√	×	-	√
Wing-grid	√	-	√	-	×
shaft	-	-	√	√	√
Two seat	×	×	×	-	×

Table4. HPA Configuration Pros & Cons

CFD Analysis of some Successful HPA's:

Here we give you a overview of whats the difference between idea of Paul mack Cready in Gosamers with Idea of Masculairs and Daedalus. Gossamers have large wing area with wing geometry of hang gliders where masculairs and daedalus has semi-rectangular wings with high aspect ratio and less wing area. This CFD Analysis was performed in QFLR5 (called XFLR5 in former versions) Software that is a panel method added to X-foil Core. Its free to use and you can download its source as well.

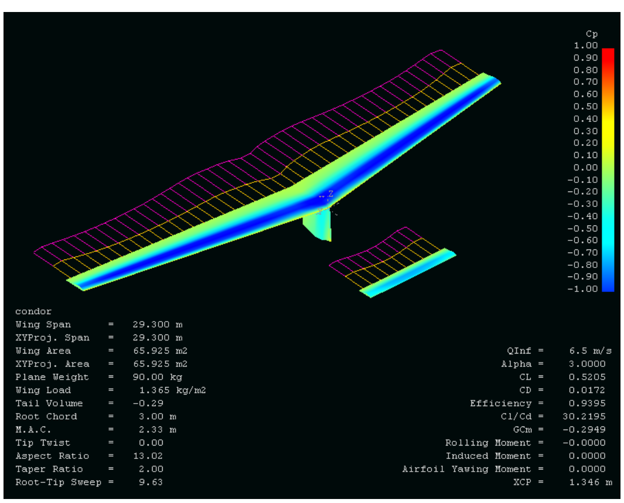


Fig 1.Gossamer Condor Model (you can see viscous and induced drag profiles)

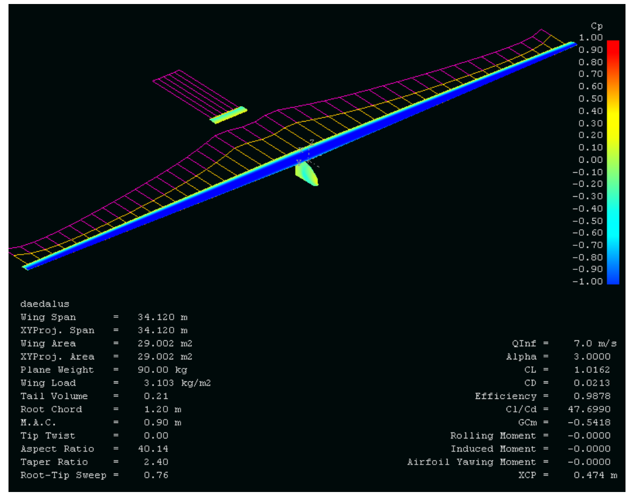


fig 2.Daedalus Model (you can see viscous and induced drag profiles)

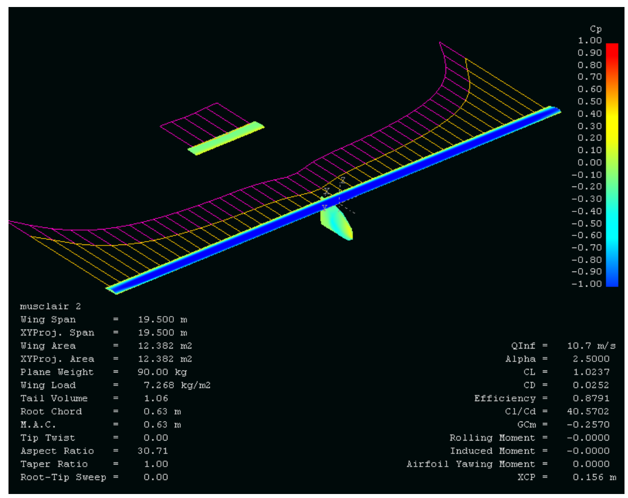


Fig 3.Masculair 2 Model (you can see viscous and induced drag profiles)

Parameter / HPA name	AR	Cl/Cd	Wing Area (m^2)
Condor	13	30.21	66
Daedalus	40	47.69	29
Masculair	30.7	40.57	12.4

Table5. Successful HPA's Wing planform Selection Results

You can see from The above results that less wing area and less AR can give you about the same CL/CD And Masculair 2 from Germany was really a final result for this historical discussion in HPA Design.

Construction methods review:

Rib Building:

for this type of aircraft weigt is extremly important because of highly limited power, fore there more aircraft should be built as light as possible. Ribs of HPA's generally were one of this types :

1) cut-outed plywood or all balsa
2) Styrofoam
3) foam with balsa edge
4) All foam rib with inlayed carbon fiber truss

Fig 4.Rib Type 4

Fig 5.Rib Type 1

Fig 6.Rib Type 3

Fig 7.Rib Type 2

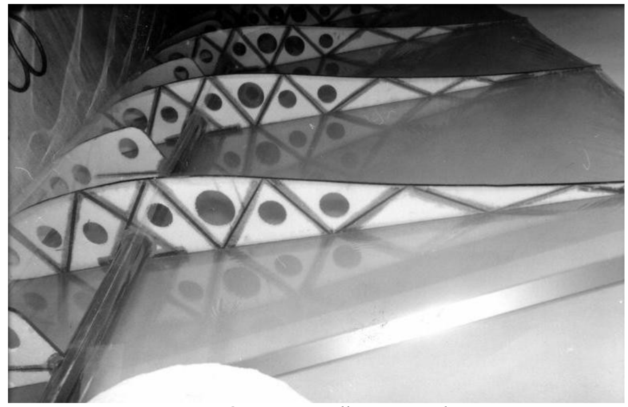


Fig 8.Gossamer Albatross Rib

Spar Building :

HPA Spar is generally one of this types:

1) Aluminum Tube
2) Carbon Fiber Tube
3) Aluminum Truss and I shaped Composite
4) Wood Truss

Fig 9.Aluminum Tube Spar

Wing Fairing :

Wing fairing was PVC films in former types and now generally from Mylar.

Tail Boom:

Tail boom was wood truss in early types and after that designers now using carbon fiber tubes and aluminum tubes.

Propeller :

Propellers have wood ribs in early types but now they are full composite props.

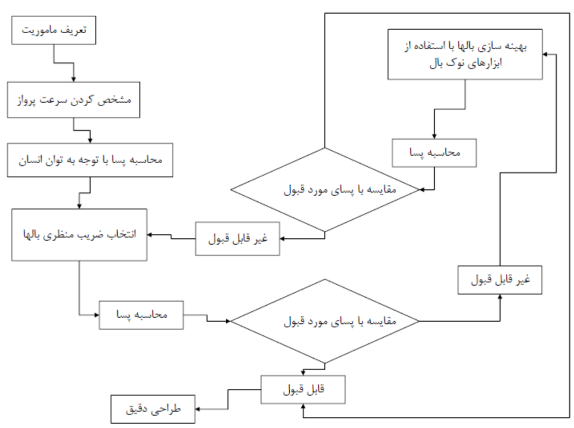
Main Cockpit Frame :

Main Cockpit frame was metal Structure but now frames are building with Aluminum and Carbon Fiber tubes.

Cost Estimation method :
RDTE
Manufacturing
Operation

Key factor analysis and Optimization :
Weight
Performance

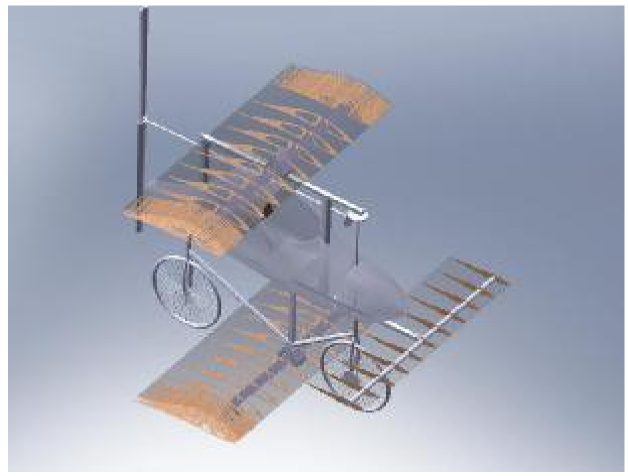
Design Cycle

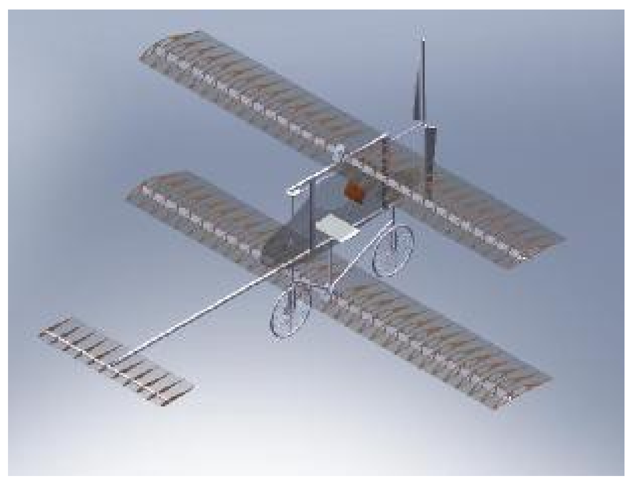


Future Applications

Now there is a plan for building a HPA for public Entertainment in Japan. Cool trust is the name of this project and the record of this HPA is 23 KM until now. The flight by this aircrafts is really joyful and every one like to test it but now the direction of this Aircrafts is competitions and it seems that it's time for a change in design direction of this Type.
We are now working on a roadable Morphing wing(retractable wing) canard HPA. You can see camputer models of this tybe below.

پارامترهای طراحی به دست آمده برای حالت پروازی	
۹۰ کیلوگرم	وزن برخاست
۱۱ متر بر ثانیه	سرعت کروز طراحی
۲۵۰ وات	توان خلبان
۱۲ مترمربع	سطح بال در حالت باز شده
۴ متر مربع	سطح بال در حالت بسته
DAE 21	نوع ایرفویل
۱.۲ متر مربع	سطح کانارد
۳ متر	قطر ملخ
۲۲.۷ نیوتن	نیروی پیشران ملخ در ۱۲۰ دور بر دقیقه
۳.۴ متر	فاصله مرکز آیرودینامیکی کانارد تا مرکز ثقل





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