Information about the author

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Educational Background
Moscow aviation institute
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Work History
Since 1976 working on ASTC ANTONOV.
Head experimental investigation department of aerodynamic
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Expert in experimental investigation of aerodynamic and design
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The laureate of the State premium of Ukraine.
The author of 12 patents for invention

PADA

July, 2009
List of the main works of the Presenter

1. Development of the methodology of turbine imitators on the models in the wind tunnels.

2. Research and refinement of aerodynamics of joint aero transport systems of large size objects on the outer attachment in wind tunnel AT-1.

3. Aerodynamic refinement of Antonov Aircrafts.
   - An-72 Layout and Coanda Effect;
   - An-124 local aerodynamics.
   - An-70 the wing aerodynamics, paratroopers safety and buffing;
   - An-140 the engine nacelle joint layout to the wing, tail section buffing problem solving;
   - An-148 local aerodynamics the aerodynamic layout refinement.

4. The layout research and aerodynamics of the Combined Wing with Custer effect for STOL and VTOL aircraft.

5. Design and construction of the aircraft with Combined Wing (Product 181).

6. Design of individual backpack Aircraft of VTOL, and model research cycle.

7. The concept development of VTOL aerial vehicles of “Fancraft” type of cascade layout.
An-72 works, Coanda effect, the wing layout.
The Universal fairing and correct layout finding to carry the largest in the world wing console of An 124 and AN 225.
The refinement of An225 Aerodynamics.
Our Team has worked on finding the optimal installment of The “Buran” (Soviet “Shuttle”) – on “Mriya” (An-225) using Wind Tunnel models.
The An-148 aerodynamics refinement.
The ARJ-21 aerodynamics refinement.
Integrated studies of Combined Wing with Custer Effect for STOL/VTOL Aircraft.
The analysis of used carrying systems of STOL/VTOL (see Chapter 1) shows that economically more advantageous are those ones, in which during transition stages, the lift is created not only by the thrust of the powerplant, but also aerodynamic forces. The Fig. 4 shows the interrelation of the lift forces during different stages of flight for different schemes of STOL/VTOL aircraft.

Resuming above shown, the perspective opportunity for economy increase rather lays in development of lift systems that augment aerodynamic component of lift during vertical and transition flight stages. In addition to that, the rational component layout of STOL/VTOL aircraft should have the following:

a) minimal geometric size and the best Weight efficiency;

b) high aerodynamic efficiency at cruise speed;

c) fitting the stability and controllability standard requirements at all flight stages;

d) optimal working conditions for the powerplant.
The existing STOL/VTOL schemes overview.

1. VTOL vehicles:

   - Helicopters and Autogyros
     + relatively high powerloadings
     + the autorotation choice for safety
     - large dimensions and related drag
     - low speed
     - low range
     - available lift is created by propeller
     thrust portion less airframe airflow
     losses.

   - Convertiplanes
     + high cruising speeds
     - large sizes
     - complex propeller and/or engine rota-
     tion systems
     - problematic use of autorotation as a
     safety choice

   - Fancraft-type vehicles.
     + relatively small size
     + relative safety for the use in confined
     airspace (cities, forests, etc.)
     - relatively low speed
     - absent the autorotation choice

2. STOL and Super-STOL airplanes.

   - Airplanes using forced wing blowing by propwash
     or turbine jet-wash (Breguet 941, or An-70,
     C17)
     + Part of lift is created by wing blowing
     factor
     - Low controllability at low speeds

   - the airplanes that use Custer-channel wing
     + high lift at low speed
     + absence of rotation mechanical ele-
     ments on the wing
     - asymmetric lift at one engine losses
     - increased blade stresses at rotation in
     semicircular shrouds.
VTOL convertible airplanes.
Super STOL airplane with propwash flap blowing systems.
STOL airplane AN-70 with the propwash blowing of the flaps.
The scheme of Custer Channel wing functioning at $V=0$ and $V_{cruising}$. 

Fig. 1  Channel wing lift at zero forward speed.

Fig. 3  Channel wing lift at forward speed $V_\infty$. 

July, 2009
General view of The Custer Channelwing CCW-5
Willard and Harold (Curley) Custer and their airplane.
The Combined Wing Scheme at the cruising and landing modes.
Choosing the optimal layout of Combined Wing.

When we tried to decide the best choice for layout of Combined Wing and relative placement of Straight Wing and Channel Section, we were following two main guidelines:

1) Placement of the propeller to be in front of highly slotted portion of Straight Wing for realization of blowing effect at it’s flaps and as a result - down deflection of the propwash. In addition, for further increase of the flaps efficiency we used tip fences.

2) Placement of the propeller plane inside of Channel Section of Combined Wing to achieve unseparable airflow of upper surface of the CS, as the result of maximal congruency of the propwash shape and top surface of CS, as well as maintaining the minimal tip gap between the prop and the surface. This is also important for lowering of tip losses and at the same time, smooth propeller blade entering and leaving the channel. This goal was achieved with the use of tip fences and their specific profiling. In addition to this, the correct positioning of SW and CS had to assure minimal harmful interferences between them. The twisted shape of propwash had caused the absence of SW leading edge slats.
The specifics of The Combined Wing layout.

The specifics of The Combined Wing layout are as follows:

- The use of closed wing scheme with minimal losses on the tip vortices, Tip fences, in meanwhile, increase effective aspect ratio of Straight Wing (SW);
- Semicircular Channel section goes around the prop providing even airflow of top surface of the semi-ring and increases the propeller efficiency due to partial elimination of tip vortices;
- The relative layout of SW and CS allows the placement of powerful multislotted flap on such straight wing, enclosed in tip fences with high turning efficiency of the propwash. Meanwhile, lowered pressure on the top surface of the Channel Section also helps to more effective downturn of propwash and further lift increase;
- The horizontal wingtip outside the tip fence of semicircular wing is destined in general to increase the aerodynamic properties at the cruising.
- At high power settings (during takeoff and landing) and propwash high intensity SW blowing, the lift of the wing tip is also increasing.
The Combined Wing Lift Components.

The principal advantage of the aerodynamic scheme of Combined Wing is the fact, that the lift of such a wing is fully using the propwash stream energy. Unlike in the indicated above systems, the lift consists of the five components:

1) $C_y$ at $p=0 + \Delta C_y$ flap – the upper mechanized wing lift without counting propwash factor;

2) $\Delta C_y$ – the lift portion caused by propwash of SW and related to it supercirculation;

3) $\Delta C_y$ p – additional lift portion as a propwash downdeflection reaction projection;

4) $C_{cs}$ at $p=0$ the Channel section wing without counting propwash factor;

5) $C_{cs} + \Delta C_{cs}$ additional lift portion of CS, caused by the pressure gradient, caused by propwash of internal surface of the channel.
The Combined Wing load distribution scheme.
The Combined Wing Calculation Scheme.
The Combined Wing MAC determining Methodology.

The lift circulation distribution on the Combined Wing semicircular wingspan investigation with and without propwash of the channel surface (Fig. 7b) had shown, that the normal forces, acting on the portions AE and KB, act in the opposite directions and are mutually cancelling each other. In addition to that, on these wing portions the airfoil is changing into symmetrical airfoil with negligible lift properties.

The normal forces projections at Y axis that are acting in the semicircular wing cross-sections gives the load distribution graph, shown, where \( Y_i = N_i \cdot \cos \gamma \).

Thus, the lift force \( Y \), acting at semicircular wing part is equal to the load distribution graphs surface acting at the projection of the semicircle AB, which allows to replace in the calculation scheme the semicircle by it’s projection that crosses the arc’s C of G, limited by the opening angle \(-60^\circ \pm +60^\circ\) from the vertical (CD portion), that lays on the 1/3 of arc’s height from it’s apex in the point M. In that case we can conditionally replace the aerodynamic scheme of the Combined Wing by simpler biplane scheme with closed upper wingtips and slotted lower wing without fuselage portion, where the top wing is combined with straight portion of top wing with constant chord placed between the fences of semiring, and horizontal wingtips. The lower wing is presented as two horizontal portions, equal to the projections of semirings.
The Combined Wing MAC calculation scheme.

The Combined Wing MAC calculations are provided in two stages. On the first stage we are finding MAC of SW portion of combined wing. The top plane with wingtip calculation on scheme is provided on slide 27. On the second stage using Bets method we determine MAC for the accepted conditional biplane scheme that corresponds to Combined Wing aerodynamic scheme. (The slide 24)

Here:  
Lsw – Top wing trailing edge span;  
Lcs – The working section’s projection wingspan;  
AB – The arc portion that corresponds to the working portion of channel section;  
CD – equivalent lower plan of biplane box of the Combined wing;  
Point E – corresponds to mathematical C of G of the AKB arc.

Hcw – The height of the cutline linking 1/3 of top wing chord and equivalent lower wing that is measured on the perpendicular to the lower wing portion;  
d – lower wing frontal staggering relative to the top wing;  
C – upper wing lateral staggering over the lower wing without the wingtip.

The calculation of the MAC to the accepted conditional biplane scheme then is done using widely known formulae that are following:

\[
  b_x = \frac{k b_1 s_1 + b_2 s_2}{k s_1 s_2}; \quad X_X = \alpha \frac{s_1}{k s_1 s_2}; \quad y_s = h \frac{s_1}{k s_1 s_2},
\]

where \( \kappa = \frac{c_1}{c_2} \)

- Is determined on Bets formula for \( C_{y_{box}} \)
- \( =0.25 \). For the Combined Wing model this ratio is at \( C_{y_{box}} =0.25 \) approximately equal 1, i.e. \( c_1 = c_2 \) and \( \kappa =1 \);

\( s_1 \) and \( s_2 \) – Projection surfaces of top and bottom biplane box planes;  
\( b_1 \) and \( b_2 \) – correspondingly MAC of the top and bottom planes of the biplane box.
The Combined Wing top plane with winglet MAC determining.
Combined Wing Aerodynamic Characteristics Calculation Methodology.

After receiving the results of Combined Wing model and the components investigation we worked out a semi-empiric methodologies to calculate the longitudinal aerodynamic characteristics of the Combined Wing.

The lift force calculations.

A total lift of Combined Wing is determined at the “mixing” method.

\[ C_{y_{kx}} = \frac{C_{y_{nk}} \cdot S_{nk} + C_{y_{kc}} \cdot S_{kc} + C_{y_{sk}} \cdot S_{sk}}{S_{x}}, \]

where \( C_{y_{nk}} \) and \( C_{y_{kc}} \) – are determined considering mutual influences of top and bottom wing;

\( C_{y_{sk}} \) – is determined with the consideration of the supercirculation influence that is created by propeller blowing at the Straight Wing;

\( S_{x} = S_{nk} + S_{kc} + S_{sk} \) – Total projected area of the Combined Wing.
The Straight Wing Lift Force.

The lift with blowing consideration is determined by the Jet Flap theory.

\[ C_{Y_{ps}} = C_{Y_{sw}} + \delta C_{Y} + \delta C_{Y_{swp}} \]

where
- \( C_{Y_{sw}} \) - lift coefficient of the Straight Wing without blowing effect;
- \( \delta C_{Y} \) - additional lift force coefficient due to the supercirculation;
- \( \delta C_{Y_{swp}} \) - additional lift force coefficient created by vertical component of down deflected propwash stream;
- \( \delta C_{Y_{swp}} \) - the SW lift coefficient component related to the influences of upper and lower wings.

\[ \delta C_{Y} = \delta C_{Y}^{\theta} \cdot 0 + \delta C_{Y}^{\alpha} \cdot \alpha \]

where
- \( \theta \) - angle of propwash deflection related to the SW profile chord;
- \( \delta C_{Y}^{\theta} \) and \( \delta C_{Y}^{\alpha} \) - augmentation of lift force coefficient derivative related to AOA and AO stream deflection with the stream reaction.

The values \( \delta C_{Y}^{\theta} \) and \( \delta C_{Y}^{\alpha} \) related to \( C_{\mu} \) are determined by the next formulae:

\[ \delta C_{Y}^{\theta} = 1.152 \sqrt{C_{\mu}^{*}} + 1.106 C_{\mu} + 0.051 C_{\mu}^{0.5} \left( \frac{1}{\rho a} \right) \]

\[ \delta C_{Y}^{\alpha} = 3.54 \sqrt{C_{\mu}^{*}} - 0.675 C_{\mu} + 0.156 C_{\mu}^{0.5} \left( \frac{1}{\rho a} \right) \]

where \( C_{\mu} = \frac{x \cdot N \cdot P}{8 \cdot S \cdot \rho g} - k \cdot B \cdot \frac{F_{y}}{S \cdot \rho g} \)

then
\[ \delta C_{Y} = \left( \delta C_{Y}^{\theta} \cdot \sin \theta + \delta C_{Y}^{\alpha} \right) \cdot \sin \left( \frac{\phi}{2} \right) \cdot \Delta L \cdot 57.3 \]

where \( \tau \) - relative profile thickness;
\( C_{\mu}^{*} \) - The AOA related lift coefficient derivative without propwash.

For the blowing case of the whole SW span.
The Channel Section Lift Coefficient.

The Channel Section Lift Coefficient (CS) without propwash

\[ C_{Y_{\text{KC}}} = \left( \frac{\pi^2}{2 + \frac{\pi}{2\lambda}} \right) \cdot \alpha_{\text{osci}}, \]

где \( \lambda \) – CS aspect ratio – \( \lambda = \frac{2R}{b} \);

\( \alpha_{\text{osci}} \) – AOA related to the Channel longitudinal axis.

The same, but with propwash action

\[ C_{Y_{\text{KC}}} = \left[ \frac{\pi^2}{2 + \frac{\pi}{2\lambda}} + C_{\text{y}}^\text{h} \cdot B \right] \cdot \alpha_{\text{osci}} + \Delta C_{Y_{\text{закр,кс}}} + \Delta C_{Y_{\text{интерф.}}}, \]

where \( C_{\text{y}} \) – empiric lift coefficient, considering semiring blowing – depended lift coefficient, as an experimentally obtained result.
The Straight Wing and Channel Section mutual interferences calculation.

The determination of $\Delta C_{Y_{\text{upper}}}$. - upper and lower wing interference.

Calculation of $\Delta C_{Y_{\text{upper}}}$ is achieved following the Betz formulae, as for the biplane scheme:

\[
C_{Y_1} = \left(1 + \frac{\mu h}{\pi \ell_{1}}\right) C_{Y_0} \rightarrow C_{Y_1} = \Delta C_{Y_{\text{upper}}} \quad \text{For the top wing (SW)};
\]

\[
C_{Y_2} = \left(1 - \frac{\mu h}{\pi \ell_{1}}\right) C_{Y_0} \rightarrow C_{Y_2} = \Delta C_{Y_{\text{upper}}} \quad \text{For the lower wing (CS)},
\]

Where $C_{Y_1}$ – average value of $C_y$ for the isolated upper wing;

$C_{Y_0}$ – average value of $C_y$ for isolated lower wing.

\[
\mu = \frac{h}{a^2 + h^2} \left(\ell_{1}^2 + h^2 - \sqrt{a^2 + h^2 + c^2}\right)
\]

Where $a$ – staggering of biplane wings;

$c$ – value of lateral wing staggering;

$h$ – average biplane box height.

The Winglet Lift Coefficient is found by the next formula.

\[
C_{Y_{\text{ws}}} = C_{Y_{\text{ws0}}} + \Delta C_{Y_{\text{ws0}}},
\]

where $C_{Y_{\text{ws0}}}$ – the winglet lift coefficient without the blowing;

$\Delta C_{Y_{\text{ws0}}}$ – SW supercirculation related winglet lift augmentation.
The Combined Wing drag calculations.

The Combined Wing total drag includes:
1. Straight Wing drag.
2. Channel Section with wing fences drag considering propwash factor.
3. The winglets drag.
4. Induced drag of the Combined Wing.

Then, the total Drag Coefficient can be determined using “mixing” rule

\[ C_{x_T} = \frac{C_{x_{p_{SW}}} \cdot S_{SW} + C_{x_{p_{CS}}} \cdot S_{CS} + C_{x_{p_{W}}} \cdot S_{W} + \Delta C_{x_I}}{S_T}, \]

where
- \( C_{x_{p_{SW}}} \) – profile drag of SW considering propwash factor;
- \( C_{x_{p_{CS}}} \) – profile drag of CS with propwash blowing of inside surface;
- \( C_{x_{p_{W}}} \) – the winglet profile drag with SW propwash blowing factor;
- \( \Delta C_{x_I} \) – Induced drag, caused by the Combined Wing total lift.
Straight Wing drag.

The Straight Wing drag portion with propwash factor is determined by the following method

\[ C_{x_{\text{пр}}_{(0-0)}} = C_{x_{\text{пр}}_{(0-0)}} + \Delta C_{x_{\text{пр}}_{\text{норм}} + (\Delta C_{x_{x_{\text{пр}}_{\text{норм}}} + \Delta C_{x_{\text{пр}}_{\text{норм}}}})}_{\text{обл}}. \]

where \( C_{x_{\text{пр}}_{(0-0)}} \) – Straight Wing friction drag with flaps without blowing factor;
\( \Delta C_{x_{\text{пр}}_{\text{норм}}} \) – airfoil unevenness related parasitic drag

\[ (\Delta C_{x_{x_{\text{пр}}_{\text{норм}}} + \Delta C_{x_{\text{пр}}_{\text{норм}}}})_{\text{обл}} = \frac{2B}{S_{\text{кр}}} \left( C_{x_{x_{\text{пр}}}} \cdot S_{\text{обл}} + 0.5 \cdot h \cdot F_{\text{в}} + \sum C_{x_{x_{\text{пр}}}} \cdot F_{\text{обл}} \right). \]

Where \( h \) – average prop disc, relative airflow slowdown by the aircraft;
\( F_{\text{в}} \) – propeller disc area;
\( k \) – number of propellers;
\( \sum C_{x_{x_{\text{пр}}}} \cdot F_{\text{обл}} \) – total parasitic drag of protruding into airflow non-lifting aircraft parts.
The Channel Section drag.

Profile drag of semicircular wing, without blowing factor we determine by the results of experimental research, where the $C_{x_{p_{ws}}} = 1.228 \cdot C_{x_p}$ of the Straight Wing with the same profile and even projection area.

In case of placement of the propeller inside semicircular wing, the top surface of the semicircle is blown by higher speed airflow than the lower surface. This evokes an additional airflow-related drag increase.

$$\Delta C_{x_{p_{ws}}} = 0.925 \cdot k \cdot C_f \cdot \eta_c \cdot \eta_u \cdot \frac{S_{0\delta_{ws}}}{S_{ws}} \cdot s,$$

where $C_f$ – flat plate drag coefficient.

$$C_f = \frac{0.072}{Re^{0.25}} \text{ (at } 10^5 < Re < 10^6 \text{) or } C_f = \left( \frac{W \cdot b}{V} \right)^{0.5}$$

where $k=1$, since only one profile side is blown at;

$\eta_c$ – Coefficient, that considers the transition from flat plate to the profile;

$\eta_u$ – Coefficient that considers air compressibility factor influence at the profile drag.

Then total profile drag of Channel Section with propwash factor inside the channel is equal to

$$C_{x_{p_{ws}}} = 1.228 \left[ 0.925 \cdot \frac{0.072}{(V \cdot b)^{0.25}} + \left( \frac{0.072}{(V \cdot b)^{0.25}} \cdot \frac{S_{0\delta_{ws}}}{S_{ws}} \right) \cdot \eta_c \cdot \eta_u \right].$$

And taking into account the interference of upper Straight Wing and Channel Section the components of profile drag $C_{x_{p_{ws}}} \ C_{x_{p_{sw}}}$ are going to be as follows:

$$C_{x_{p_{ws}}} = C_{x_{p_{sw}}} \cdot \frac{C_{x_{ws}}}{C_{y_{ws}}}$$

$$C_{x_{p_{sw}}} = C_{x_{p_{sw}}} \cdot \frac{C_{x_{sw}}}{C_{y_{sw}}}$$

where $C_{x_{p_{sw}}}$ and $C_{x_{p_{sw}}}$ – total profile drag coefficients of isolated Straight Wing and Channel Section.
The Combined Wing Induced Drag Calculations

The Combined Wing Induced drag component we determine by the Prandtl formula (as for a biplane)

$$\Delta C_{x_i} = \frac{S_{\Sigma}}{\pi \cdot \ell_{\Sigma KB}^2 + 4F \cdot C_y^2}$$

where $S_{\Sigma}$ – Total projection area of the Combined Wing (upper and lower);

$F$ – The contour area between the straight and channel sections at frontal view;

$\ell_{\Sigma KB}$ – Equivalent upper wingspan;

$C_y$ – The Combined Wing total lift coefficient.
Combined Wing Longitudinal Moment calculations.

Combined Wing longitudinal moment calculations we provide by Betz method (as for the biplane box), according to the below scheme

\[
M_{x_i} = q \cdot S_i \cdot b_i \left( C_{m_i} - C_{y_i} \frac{X_i}{b_i} - C_{x_i} \frac{Y_i}{b_i} \right)
\]

\[
M_{x_j} = q \cdot S_j \cdot b_j \left( C_{m_j} - C_{y_j} \frac{X_j}{b_j} - C_{x_j} \frac{Y_j}{b_j} \right)
\]

\[C_{m_i} \text{ and } C_{m_j} \text{ – the upper and lower wing moment coefficients, leading edge related and determined by the formula}
\]

\[
= C_{m_i} + \frac{dC_{m}}{dC_y} \cdot C_{y_i}
\]

where \( C_{m_i} \) – Profile moment coefficient at \( C_y = 0 \).

The total longitudinal moment coefficient is determined as the sum

\[
M_{z_2} = M_{z_i} + M_{z_j} + \Delta M_p \quad \text{H} \quad C_{m_2} = \frac{M_{z_2}}{q \cdot S_2 \cdot b_2}
\]

\( \Delta M_{z_2} \) – Propeller thrust longitudinal moment portion.

The \( C_{m_i} \) and \( C_{m_j} \) coefficients in previous formulae are determined with correction for upper and lower wing influences

\[
C_{m_i} = C_{m_i} \frac{C_{y_i}}{C_{y_j}} \quad \quad C_{m_j} = C_{m_j} \frac{C_{y_j}}{C_{y_i}}
\]
The Combined Wing structural scheme choices.

The effective structural scheme of the Combined Wing is one of the advantages of this airplane. This is due to relatively rigid construction of channel section, which provides the function of upper wing strut.

In order to have the best choice we provided the calculations for the following versions:

Version 1 – considers rigid wing-to-fuselage attachment of the Straight Wing and Channel Section and pivoted joint of CS outside margin to the SW.

Version 2 – considers rigid joint of SW at the fuselage and rigid joint of CS outer section with SW and pivot joint of the CS – to- fuselage.

Version 3 - considers rigid joint of SW at the Fuselage and pivot joint of CS to fuselage and SW.

Version 4 - considers rigid joint of all the connections.

Version 5 – considers rigid SW –to-fuselage joint and pivot joints of both CS section to the SW.

Our comparative analysis had been based on the An-74 aircraft for the original wing and Combined Wing.

As the startup conditions we had the following:

1. An-74 take-off weight – Go=30t.
2. The original wingspan of An-74 – &ep=31.9m.
3. Wing area – Skp=98.5sq.m.
5. Equivalent Combined Wing total projection area – Skp=70m².

The total calculated single wing console loading for both cases had been determined by the following formula:

\[ P_p = \left( \frac{G_0}{2} \cdot n_3 \cdot K_{\text{SKR}} \right) = 15 \cdot 2.5 \cdot 1.5 = 60t \]

where \( n_3 \) – useful overload upper limit is, \( n_3=2.5; \)

K_{SKR} – Calculation Stress Reserve Coefficient

K_{SKR}=1.5.
Load distribution scheme for the An-74 with original and Combined Wing versions.
Finite Element Analysis scheme of the Combined Wing.
Bending Moment Scheme for original and Combined Wing
Bending Moment Scheme for different joint types of Combined Wing elements.
The Combined Wing advantages.

Such a layout construction scheme uses the advantages of strut system, since relatively rigid structure of semicircular wing plays the role of the upper wing strut and rationally attached to the fuselage, allows for considerable load relief of wing elements as well as of whole airplane.

This way the proposed Combined Wing allows for:

- the maximal use of the power possibilities of the engine to provide the aerodynamic lift force (one powerplant assures for the airflow of doubled wing surfaces) and we achieve more aerodynamic lift gain \( \Delta C_y \) per power unit plus lift force of propwash downward redirection at take-off and landing regimes);
- weight decrease of the wing by using rigid 3dimensional attachment scheme and considerable decrease of the size and needed wing surface;
- Diminish the noise by the propeller and propwash screening inside Channel Section;
- Improve maintenance conditions and safety by propeller shrouding;
- Effective thrust increase at slow speeds due to lowering tip losses in Channel Section;
- Assure The maximum aerodynamic value of the airplane in the cruise at the existing regular plane level, but with considerably smaller wing dimensions (due to lower tip losses) with the presence of tip fences and larger total aspect ratio of Combined Wing with winglets.
The Combined Wing properties comparison.

The comparison of the Combined Wing with the biplane wing shows that the biplane wing with the same geometric dimensions has 1.5 times lower aerodynamic value due to its high wing bracing drag and higher induced drag tip losses. In addition, the efficiency of the wing propwash blowing is not present.

The usual straight wing with equal aspect ratio and the same powerplant is considerably loses to the Combined Wing with its lift capacity with propwash blown surface area.

The swept wings are even less using the forced wing surface blowing factor and respectively – the energetic possibilities of the powerplant to assure STOL and VTOL capacities.
Experimental Research of Combined Wing aerodynamics on wind tunnel models.

Wind tunnel testing of channel and Combined Wing had been essential to obtain experimental data and final correction of our semi-empiric methods of aerodynamics calculation of the airplanes with Combined Wings.

The experimental research program considered the testing of the following model rows:
The Isolated Channel wing model without and with working powerplant modeling (model 1-78);
The isolated Combined Wing model with the possibility of separate parts testing without and with working powerplant modeling. (models 2-80 and 03MK181.001);
Schematic airplane model with combined wing (01D.MC87K.001);
Mock-up models on the main themes of the enterprise with Combined Wing applications (01Г.MC87.001);
Initial Experimental airplane model with the Combined Wing to investigate wing surface pressure distribution (01Д.MC87K.001);
Executive model of experimental airplane with powerplant action modeling (25MC181.001);
Aerodynamic model of Backpack VTOL aircraft (BA product) with powerplant action modeling (01 MC.PC.001);
Remotely controlled Backpack Aircraft(BA) VTOL model for flight testing research (02MC.PC.ДП.ЛА);
Executive aerodynamic model of BA product with engine nacelle mockups.
The Channel Wing Model
The Channel Wing Model in AT-1 wind tunnel with piston engine.
Combined Wing in cruise configuration.
Combined Wing model in landing configuration.
Combined Wing model in AT-1 wind tunnel with engine imitator.
The aerodynamics comparison of Combined Wing, Straight Wing and Channel Section.

Comparing the aerodynamics of the Combined Wing model (at $\delta z=0$) and its isolated components (SW and CS) shows that at equal top view projection dimensions the maximum lift force of the model is proportional to the multiplication $C_{y_{\text{max}}}S_{\text{ap}}$, for the Combined Wing is considerably higher, than for the separate CW components. (SW, or CS)

<table>
<thead>
<tr>
<th>The model layout versions</th>
<th>Typical coefficients</th>
<th>$\delta_{z_{\text{sw}}}=\delta_{z_{\text{cw}}}=0$</th>
<th>$\delta_{z_{\text{sw}}}=66^\circ$</th>
<th>$\delta_{z_{\text{cw}}}=76^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_{y_{\text{max}}}S_{\text{ap}}$</td>
<td>$a_{\text{tip}}$</td>
<td>$a_{\text{tip}}$</td>
<td>$a_{\text{tip}}$</td>
</tr>
<tr>
<td>Combined Wing</td>
<td>0.145</td>
<td>24</td>
<td>0.014</td>
<td>0.299</td>
</tr>
<tr>
<td>SW portion with the tip fences</td>
<td>0.069</td>
<td>12</td>
<td>0.014</td>
<td>0.219</td>
</tr>
<tr>
<td>Channel section with fences</td>
<td>0.095</td>
<td>18</td>
<td>0.020</td>
<td>0.148</td>
</tr>
</tbody>
</table>

The maximum lift of Combined Wing is somewhat lower, than the sum of the lift of its separate parts due to interferences of the top and the bottom wings and this difference for the models at $\delta z=0$ is about 11% and at $\delta z=66^\circ/76^\circ$ is about 19%.

Positive layout effect of Combined Wing is reflected on the frontal drag, where the minimum frontal drag coefficient of Combined Wing is the same as SW portion with the fences and lower than the at the CS.

The longitudinal static balance of Combined Wing model also somewhat better than at isolated SW and CS.

The comparison of the static model aerodynamics show, that at equal geometric top view sizes the Combined Wing has the biggest lift force (proportional $C_{y}\cdot S$) and considerably higher values $a_{\text{tip}}$ (almost 10° higher than for the straight wing), but is inferior to other layouts in maximum aerodynamic value due to considerably lower aspect ratio. It can be well increased by the horizontal winglets installment.
The $C_{y}(\alpha)$ Chart of Combined Wing, Straight Wing and Channel Section models.

S – projectional
The L/D charts of the of Combined Wing, Straight Wing and Channel Section models.
The $C_y(\alpha)$ chart of Combined Wing model with engine.
Combined Wing \(C_y(\alpha)\) chart (no engine) for two placements of the Straight Wing inside Channel Section (anterior and posterior Straight Wing positions).
L/D ratio chart of the combined wing without engine (frontal and posterior Straight Wing positions).
The Cy(B) chart to evaluate the placement of the propeller in the Channel Section.

- Where \( B = \frac{Prop\text{thrust}}{Prop \text{ area}} \times \text{Speed Pressure} \)
The Combined Wing aircraft model without winglets.
The Combined Wing model with winglet type ZK-4 in landing configuration.
The Combined Wing model with winglet ZK-4 in cruising.
The aircraft model with Combined Wing with engine.
Aircraft model with Straight Wing, Tip Fence and Winglet.
The model of Channeled Wing in third position (classic Custer) with winglet.
The airplane model with equivalent Straight Wing.
The scheme of the investigated propeller placements inside Channel Section in Custer version (without Straight Wing).
The aircraft model with Combined Wing and winglet aerodynamics with no engine.
L/D charts with combined wing and winglet without engine.
Longitudinal stability chart $m_z(\alpha)$ of the model with Combined Wing and winglet with no engine.
The Aerodynamic Quality $K(Cy)$ comparison of different models in wind tunnel AT-1.
The $C_y(\alpha)$ graph of the model with Combined Wing and winglet at $\delta_3=0$ (flap cruise position) with engine on.
The Cy(\(\alpha\)) graph of the model with Combined Wing and winglet at \(\delta_3=66/76\) with engine on.
The Cy(α) graph of the model with Combined Wing and winglet at δ3=76/76 with engine on.
$C_Y(\alpha)$ of the model with Combined Wing and winglet with engine on in cruise, take-off and landing configuration.
L/D ratio ($C_y/C_x$) of the model with Combined Wing and winglet with engine on in cruise, take-off and landing configuration.
The lift comparison of the same model with Combine Wing, Straight Wing and Custer Channel Wing.
Lift Coefficient of the model with Custer channelwing for two propeller positions.
The Experimental airplane with Combined Wing (product 181).

Based on described above research data of the aircraft layouts with Combined Wing in 1986 the “Antonov” bureau came up with the decision to construction of light experimental aircraft with Combined Wing.

This aircraft (product 181) had been assigned for the in-flight investigations of aerodynamic properties of the Combined Wing aircraft, as well as to research it in the critical regimes in the full size wind tunnel.

The aircraft also is to be used as light multi-purpose aerial vehicle with the option to use it off small unprepared land spots.

Aircraft construction.

The main feature of the aircraft is the use of Combined Wing that consists of Straight Upper wing, semi-circular lower wings with outer tips formed as tip fences, limiting the overflow at the upper straight wing; furthermore, with horizontal winglets installed at tip fence’s outer sides.

The straight wing with NACA-23014 profile has two-slotted flaps with the propwash blowing option at whole span, aileron interceptors and final approach interceptors.

The working parts of lower semi-circular wing throughout 120 deg. arch have constant Go593 profile with 12% relative thickness that on the outer side gradually changes into symmetric profile of the tip fence, and at internal side of the semi-ring is transitioning into wing- to-fuselage fairing.

Removable winglets of high aspect ratio 3K4 with c5-15 considerably increase total aerodynamic quality of the aircraft.
The fuselage construction.

The fuselage all metal monocoque with oval cross-section (1,05m×1,05m), 6,2m length and spindle shaped body consisting of 4 parts.

The 2 seat cabin is located in the forward part. The entrance is achieved through the up-and-backward removable canopy.

The middle part is the load bearing wing attachment compartment. It contains the fuel and lubrication systems.

Behind the load bearing section there is engine compartment. The fuselage tail section is the load bearing structure to the tail unit attachment.

Tail unit is all-metal, V-shaped, consists of two arrow shaped consoles, installed at 45 deg to the Symmetry Plane of the aircraft.

The engine is 140 hp, turbocharged Walter Minor M-332.

Immediately on the engine shaft there is a propeller break system.

The powertrain is constructed as follows: Central shaft – Central reduction drive – two sideshafts – two angle drives that turn two counterrotating, fixed pitch 5 ft propellers.
Control System.

The control system is of single type with central stick.

The manual control and foot control are of standard airplane type.

The linkage is mixed (push-pull rods and cables).

The longitudinal directional control is achieved by symmetrical rudder deflection.

The trimming is electrical on the rudders.

The banking control is achieved with the means of aileron-interceptors that are placed on the outer part of the Straight Wing span portion.

The yaw control is obtained by asymmetric foot controlled rudder deflection.

The approach angle control is obtained by the approach interceptors, that we had placed on inward portion of Straight Wing span.

During landing roll these ones are used as airbreaks.

The aircraft has Trike type non retractable chassis.
The Airplane general view.
Front View.
Upper View.
Right View $\delta_3=65$ of the flap.
Left View. Flap deflection $\delta_3=0$. 
Rear View with flap deflection angle $\delta_3=65$. 

July, 2009
The Cabin.
The airplane at the exhibition of 1990 г.
The airplane in the year of 2009.
The three-dimensional layout scheme.
The Layout (Top View).
Mean Technical Data of the Experimental Aircraft
(Product 181)

Number of seats: 2;
Crew: 1;
Length: 7.31m;
Wingspan (with the winglet): 7.30m;
Height: 2.33m;
Total Wing Area: 7.0m²;
The Combined Wing Aspect Ratio: 7.61;
Gross Weight: 545kg;
Min TOV: 650kg;
MATOG: 820kg;
Fuel Weight: 84kg;
Max Horizontal Speed: 225km/hr;
Minimal Horizontal Speed: 57km/hr;
Range: 530km;
Service Ceiling: 4200m;
Take-off and landing roll: 70/80m;
Take-off Speed: 70km/hr;
Landing Speed: 80km/hr.
# Main Technical Data of the Combined Wing Aircraft Types

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<th>Units</th>
<th>Values</th>
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Experimental Research of the Product 181.

Wind Tunnel Model Research.

In order to assure the startup data to aircraft aerodynamic calculation and determining the aerial loading of Combined Wing we had designed, produced and researched in the wind tunnel AT-1 the 1:3.7 scaled model of The Product 181.

The Model had offered the choice of testing with the engine nacelles and propeller engines. In addition, on the left wing of the model we produced the drainage of the components of Combined Wing in five cross-sections in order to determine the pressure distribution in the Combined Wing cross-sections.

To analyze the flight properties in the cruise ($\delta_3=0$), takeoff ($\delta_3=45^\circ$), and landing ($\delta_3=65^\circ$) configuration we calculated the existing flight envelope,

The calculation results of flight and take-off data, as well as stability and controllability had confirmed fillment of the Soviet and Ukrainian Flight Safety and Airworthiness Requirements.

Stand testing.

In order to determine the working capacities of the aircraft and its TBO we had built a special power installment stand, where we had gone through a number of transmission complexes, having confirmed initially intended transmission resource of non less than 50 hrs.
The Model of The Product 181 in the Wind Tunnel.
The AOA dependent Lift Coefficient $C_y(\alpha)$ of the Airplane 181 at Zero Flap Deflection Angle ($\delta_f=0^\circ$).
The AOA dependent Lift Coefficient $C_y(\alpha)$ of the Airplane 181 at 45° Flap Deflection Angle ($\delta_f=45°$).
The AOA dependent Lift Coefficient $C_y(\alpha)$ of the Airplane 181 at 65° Flap Deflection Angle ($\delta_f=65°$).
Needed and Available Thrust of 181 Airplane 181.
The Engine of the Experimental Airplane.

**Description of Model LOM M 322 A**

The LOM M 322 A is an ignition, 4-stroke, 4-cylinder, in-line, inverted engine with low pressure fuel injection to the intake valve port. The engine is supercharged by a geared, disengagable centrifugal compressor with small compression ratio. The propeller drive is direct. The valve operating mechanism is OHV type. The inlet and exhaust ports are opposite. With the engine can be used variable pitch propeller, electrically or hydraulically governed. The engine is also equipped with a starter and a generator and is provided with outputs for hydraulic and propeller governor drive.

**Technical Specifications**

- No. of Cylinders: 4
- Bore (Inches): 4.13
- Stroke (Inches): 4.53
- Displacement (Cubic Inches): 214.8
- Compression Ratio: 6.3:1
- Propeller Drive: Direct
- Take-Off RPM: 2700
- Cruising RPM: 2500
- Recommended Fuel (OCT): 70
- Crankshaft Rotation: c/0; ccw
- Dry Weight (lbs): 224

**Altitude Characteristics**

1. Power (BHP)
2. Specific Fuel Consumption (LB/Hp.h)
3. Engine speed (RPM)
4. Altitude (Feet)
5. Power Curve, Not Supercharged (BHP)
6. Power Curve, Supercharged (BHP)
7. Specific Fuel Consumption, Not Supercharged (LB/Hp.h)
8. Specific Fuel Consumption Supercharged (LB/Hp.h)
The Powerplant Testbed of 181
The Powerplant Testbed of 181
The Envelope of 181 at $\delta_3=0^\circ \ G_0=650$ kg.
The Envelope of 181 at $\delta_3=45^\circ$ $G_0=650$ kg.
The Envelope of 181 at $\delta_3=65^\circ$ $G_0=650$ kg.
The Ultralight Backpack VTOL Project with Combined Wing.
(The BA Project)

The history of VTOL Backpack Aircraft and their classification.

At the end of fifties the designers started creating Backpack flying vehicles. Within that time they developed and tested a number of types of such constructions but until now they had been only prototype samples.

Classification of Backpack VTOL Aircraft.

1. Jet powered Backpack VTOL Aircraft
   - The jet belt with Hydrogen Peroxide engine;
   - Jet belt with mini Solid Fuel Jet;
   - The Homo Avic project with the wings.
2. Backpack VTOL Aircraft with the propellers;
   - The Solo Trek;
   - The Martin Jetpark.
3. Backpack Aircraft with flexible wing and Pushing propeller.

The sketch project of Backpack VTOL Aircraft was developed in 1989 based on previously tested Combined Wing models.

During the period between the April and August of 1996 we designed and produced remotely controlled model of this aircraft in 1:3 scale. Furthermore this model had passed a number of Tunnel and Stand tests, including flying tests on VTOL modes, hovering and landing on the tied up stand that had confirmed the possibility of such a scheme and its claimed characteristics.

The aircraft is meant to be used, as an individual VTOL multipurpose flying machine. The aircraft general view is provided on the Fig. 35,36.

Recently the similar research is provided in the USA (Solo Trek, Martin Jetpack).
The VTOL Heinkel Lerche Project - 1945.
The Homo Avis Project.

Single-engine prototype, powered by turbojet, develops 176 pounds thrust in pod over wing (shown suspended).

Ultimate-form Homo Avis will have twin ducted-fan engines, complex variable-geometry wing.
Backpack VTOL Aircraft  Trek Springtail

Current development version of Trek Springtail EFV-4B, nicknamed ‘Bluey’
Backpack VTOL Aircraft  Martin Jetpack
Experimental VTOL aircraft XFY-1 Pogo
The advantages and disadvantages of Backpack VTOL Aircraft.

The advantages and disadvantages of Backpack VTOL Aircraft with vertical body in horizontal position.

+ Simplicity of design.
+ The absence of transition stages with changes of body position.
  – Low speed.
  – At all the stages the lift is created using only propeller thrust.
  – Low range.
Backpack VTOL Aircraft with Combined Wing.

The Aircraft Design features.

The airframe is produced of CM that assure for low weight and acceptable strength.

The Combined Wing provides small transverse sizes; high lifting quality of the wing on transition stages; increases the propellers efficiency in the channel; lowers the noise; increases the safety on the limited space places.

Twin rudder tail scheme fulfills the role of standing points on the ground; assures the high steering efficiencies of the tail surfaces placed in the propwash stream at all flying stages.

The installment of two rotary engines on the wing, linked with the common transmission shaft assures good engine cooling at all the stages; increases the safety in case of one engine loss.

Four bladed propellers with hydraulic adjustable pitch prop are providing reliable and efficient powerplant operation at all the stages.

Closed pilot cabin and protected control handles are responsible for good aircraft aerodynamics, high speed and comfort.

The BRS recovery system can provide for safe landing in case of both engines failure.

The landing devices that consist of main and emergency shock absorbers can assure safe landing at vertical landing speed up to 6m/sec and at any unprepared spot with 4x4m.
Backpack VTOL Aircraft with The Combined Wing.

The aircraft exploiting features.

The takeoff and landing are done vertically with further transition in horizontal position at speed building and in horizontal flight.

The control in vertical flight is achieved by the same means of control as in horizontal flight with two control handles that can provide for sideways shifts relating to the flight trajectory without spatial pilot orientation.

With one engine loss the aircraft continues the flight and lands with emergency shock absorbers and BRS system.

In Three engine version Mk3 the vertical landing is possible with one engine loss.

Applications of the aircraft.

– individual flying vehicle of “Air Motorcycle”;
– courier, scouting, observation, aerial photography, Search and Resque assignments;
– patrol;
– possibility of be used of land limited places, any ships aircrafts and other carriers;
– possibility of UAV versions and back – and forth switching.
– The simplicity and the ease of piloting allow for easy training on special short courses with the use of the simulators and tied on-rope stands.
Projections of the Backpack VTOL Aircraft.
Layout Scheme of BA.
The Flight Trajectory of BA Product on Transition Stages.
The Model of the BA (Мк-1)
The Model of the BA (Мк-1)
General view of BA parked.
General View of flying BA(Mk-2).
General View of BA (Мк-2).
The proposed engine BA.
The Flight Envelope of BA(Мк-1)
## Tech Characteristics of the versions of BA product (Ariel) and its comparison with the analogical vehicles

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The experimental research of project BA.

The main goals of the research are the following.

- The determination of the main aerodynamics of the model and the layout establishment in wind tunnel.
- The determining of the vertical takeoff and landing and hovering near the ground and at the altitude during tied down stand testing;
- The model behavior during the transition stages from vertical - to horizontal and vice versa at free flight testing;
- The refinement of the control methodology at vertical and transition stages on the tied up stand and in the free flight;

On the research first stage in the wind tunnel and in the tied up stand in 1997 the model has been using the electrical wire delivered power and the micro electrical engines - 3 kilowatt each.

On the second stage for the free flight the model had been equipped with the piston engines with up to 5hp each. According to the results of the wind tunnel testing, the aerodynamic layout had been refined and the main aerodynamics of the model established.

On the research on the tied up stand 58 flights in 21 day had been accomplished with an average duration about 5 minutes each.

In the process of these researches the methodology of control had been worked out and an acceptable stability and controllability of the model on the regimes of vertical take off, hovering and maneuvering at hovering and and vertical landing.
Model of BA and internal components and control systems.
Remotely controlled model of BA.
Internal Model Control Appliances.
Testing on the tied up stand.
Testing on the tied up stand.
BA model with piston engines
Модель издел BA model with piston engines in the wind tunnel
AT-1

ASTC ANTONOV

PADA

July, 2009
BA model with piston engines on the stand.
Testing on the tied up stand.
Free flight model testing.
The BA model in the wind tunnel.
The BA model in the wind tunnel.
The BA model in the wind tunnel.
Aerodynamics of the BA model.

With the winglets and without winglets
Present works situation on BA.

The results of completed calculations and experimental research on the BA models allow to conclude, that the Combined Wing for the Backpack Airplane assures good properties in the vertical take-off and landing, as well as on transition stages and cruise at the fuselage horizontal position. To increase the range the aircraft could be equipped with the removable winglets.

The aerodynamics of the BA allow for the flight characteristics considerably ahead of existing in the world known models.

In the future we assume the full size mockup, powerplant stand and experimental flying prototype.

The choice of Combined Wing for BA provides good horizontal flight properties in cruise, considerably surpassing the known analogical models.
The proposed scheme of the passenger plane with Combined Wings.
Takeoff of the airplane with Combined Wings.
Conclusion.

As a result of the completed complex works of the Combined Wing on the wind tunnel and theoretical works we established the optimal layout of the Combined Wing with Custer Effect. It can be used on VTOL and STOL airplanes.

It is possible to evaluate the advantages and disadvantages of this wing in comparison with straight wing with flaps and slats and Custer Channelwing.

The established methodology of MAC of Combined Wing can be used to MAC calculation of the combined wings of any layouts, with different winglets, or without them.

The results can be used in the future to determine the aerodynamics and C of G calculations.

The methodology of longitudinal aerodynamics of Combined Wing is established.

Analytically evaluated is the construction layout of Combined Wing for the optimally loaded construction.

Proposed Combined Wing scheme for STOL/VTOL aircraft allows to obtain considerable advantages of takeoff and landing performance of the Combined Wing with the propeller wash blowing factor.

Relatively rigid construction of the Combined Wing offers significantly lower the stresses on the wing elements and assure further weight reductions of the airplane, so – increase its weight efficiency

The application of the Combined Wing is reasonable to the middle and light regional propeller aircraft at $M_{crus.} \leq 0.5$, in General Aviation and personal VTOL aircraft.
The End.