ADVANCED AGRICULTURE AIRCRAFT - PRIMARY DESIGN

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Abstract

For respectively long period of time the agriculture planes has not been changing in their main form. Most of designs are based on the projects first drawn in 40's and 50's. Basically the structures are good but it could be possible to make ag-operations easier and cheaper.

The safety of operations is the most important factor in ag-operations so all available details about the air accidents were investigated. Some economical and operational factors of the operations were reviewed.

Basic general arrangement drawings were prepared showing the concept and planes development. As a basic concept the canard configuration was chosen because of its advantages for safety. Also it was found that this configuration may offer other profits to plane and its operator.

The structural solutions were also prepared to solve technological problems having serious influence on the structure.

To check the concept a lot of aerodynamical and mass calculations were done. Those proved the important relations in he plane balance and aerodynamical configurations which were under detailed calculations.

To check final concept big radio control model was build to preside with flight tests.

1. The situation at the ag-plane's market.

For respectively long period of time the agriculture planes has not been changing in their main form. The traditional configuration engine - hopper - cockpit and low wing monoplane is dominating market. Few biplanes and types with hopper bellow cockpit are still in production however. Most of designs are the logical development from designs drawn in late 40's and 50's. Basically their structures are good and production costs are reduced to minimum because of long production.

The agriculture planes market seems to be very traditional if not even conservative. This is mainly because of mental factors of its final user the agriculture pilot which is in most cases good pilot but with very low education in theory of aviation. This is why the modification and innovations are not warmly welcomed by them. The other important factor is that most of manufacturers reduced the size of their company to minimum and factored into single market. As a consequence non of companies had enough

financial background to create modern ag-plane. Under those conditions the recession made serious damages to the manufacturer's market and all of them had to slow down production. In some causes it was lead to production canceletion or even company was bancraption.
The US market with over 8000 planes in service was the widest and local manufacturers like Air Tractor Ayres and Shweitzer were hit directly.
But not only. The Polish company WSK Mielec with PZL M-18 Dromader also faced problems as USA was the most important market.

In mid 80's at Warsaw located the WSK-Okecie aviation factory the idea about new agriculture plane was created. New plane was targeted as a replacement of currently produced PZL-106 model with 1.5 cm hopper and over 200 planes operated in Europe, Africa and Middle East.

2. The close look at the market and its needs.

The main goals to be achieved by new type were: safety, low cost and easy to fly and maintain. Also plane had to offer better operational performance to do the same job faster and cheaper. But the main goal was the security. This is why the standard configuration engine - hopper - pilot was chosen as a basic and excluded from any future modifications.
One of the very first jobs was the closed look at the safety and accidents during agriculture operations. Almost 200 events were carefully reviewed with range wide from dangerous situations to the accidents with casualties.
Those last were under special look of course. It was found out that most of casualties - non aircraft related - were caused by broking operational requirements without any coincidences with the plane's configuration. But the remaining group - aircraft related - was mainly caused because of stall on main wing under difficult or emergency situations. This was an important factor supporting initial idea of canard configuration.
In non-casualties group the serious number of accidents which occurred during ag-operation showed structural damages to the front part of fuselage and wings causing aircraft scraping. In case of having the other structural part in front of plane both main wing and fuselage could be safe or damages would be repairable. This would safe a lot of money to the operators.

To reduce purchase costs two solutions were possible either low cost manufacturing, cheep materials, primitive technologies or long time production with use of all advantages of todays aviation technology. First solution was possible but problems with matching other requirements like low operational costs could create future loses.
The big number of planes could be achieved by creating family with high percentage of commonalty between offered models.
Lower price was possible to achieve thank to lower labor costs expected in Poland.

Engines used on most of newly manufactured ag-planes are mainly modern expensive turboprops. This is against low purchase cost but on the other hand, with present popularity of turboprops, maintenance is allowed in each local workshop.
The safety reasons are requiring decreasing power loading and at present moment the strong piston engines are simply not available at the market. The second hand stock of II World War engines is serious but limited.
The jet fuel is more popular and cheaper than the avgas used mainly for club planes. In some region jet is only available fuel and turboprops are required.
The domestic engines or imported from the same economical zone were recommended not only because of additional expanses but also because of service and overhauls.

Simple and compact construction was necessary to reduce production costs as well as operational costs by cutting work load necessary to keep plane flying. The number of on ground operations and preflight check points had to be reduced to minimum. The concepts of future service had to be created in the modern philosophy including periodic checks and overhauls.

The corrosion resistance was one of most important problems of long period service. Because of using fertilizers, often mixed with water, the metal aggressive mixture was in contact with many parts of plane. This was adding problems to the operators forcing them to keep larger ground staff responsible for structural inspections and everyday service including washing. Always some of the mixture was penetrating the rear part of fuselage causing some damages. The overhauls and repairs were extremely expensive because of required procedures with scanning often found necessary. To reduce those costs corrosion resistance materials were necessary. If composites were used the goal of reducing every day maintenance could be achieved.

The reduction of operational costs could be achieved with reduction of fuel burn and higher life time of plane. The easy access to hopper while loading it could allow to cut on ground time. The other savings could be found on the way airfield-sprayed field and back could reduce investments. Also the turns if allowed to be thinner were offering some savings as well. But those were requiring cleaner plane and safer and even resistant for the stall.

Pilot had to be offered modern cockpit understand as a work place where pilot spends long time working in permanent stress. Visibility is the most important problem but also conditioning and good ergonomy, allowing different pilots to find cockpit suitable for them, were required.

The provision of second place for mechanic, joining pilot for for ferry flights, and tank allowing ferry operations without special preflight modifications could make new plane much more flexible and more attractive for potential operators.

3. The design.

After the reviewing market needs the canard configuration looked very promising covering most of initial factors. But there were still some additional questions to be answered and unsolved problems.

The main factor was the safety of course. This is why the standard solution engine - hopper - pilot was agreed as a basic concept without provision for any modifications.

The canard could play significant part in the energy absorption while hitting ground or ground obstalce The other advantage was possibility to produce much higher dynamic lift in case of emergency situation and necessity of over flying any obstalances. On the other hand it was obvious that it may have negative influence on the visibility from cockpit.

It was found out the wire hitting was typical collision during ag-operations. In most cases plane was undamaged but serious loses were being done to local economies because of brakes in the electricity supplying or contact by phone. For canard hitting wires was more dangerous than for conventional plane while cutting them with undercarriage.

The other factor with canard was an interference between front and rear lifting surfaces. In case the tip vortex was hitting leading edge of main wing serious problems with stability may appear. (Such problems were found in the OMAC - 1) To omit this problem the vertical separation was necessary between both surfaces. Because of visibility canard had to be moved downwards. The structural and aerodynamic requirements did not allow fuselage to expand to close to the ground and as a consequence the anhedral was chosen.

The main wing had to have dihedral to stabilize plane especially to compensate anstabilizing influence of the canard. After several calculations the simple model was built and tested proving both anhedral and dihedral.

The wing sweep was necessary for directional stability. Fuselage was short to reduce weight so the additional surfaces had to be used instead of conventional fin. This lead to two wing-tip fins on the both wings.

Wing tips were to play main role in the planes control but also were equipped with small wheels to protect plane while taxing with side wind and turning.

Fuselage was created by necessity to put both lifting surfaces and engine together as well as housing hopper and pilot. There were no serious problems with this a part from that pilot had to seat enough high to have satisfactory visibility. It was impossible to solve problem of fuselage composition to have it with less drag or some lift.

The optional second seat was placed behind pilot. This could be occupied by mechanic while ferrying or by instructor in plane modified for training. Such solution was required by experience with training young pilots in Poland and East Germany as their way to the ag-aviation was different from this typical for Western pilots. Probably even Western operators could find such solution worth to invest.

The canard configuration was allowing more compact structure. Fuselage length was limited to distance necessary to connect canard and main wing together. At the same time the separation between canard and wing was allowing easy and save loading of fertilizers to hopper. The operation could be carried on without shooting down engine because personnel and equipment were safe from propeller while operating behind canard. Loading with engine working at its minimum RPM was reducing time on ground by 25% almost without increase of fuel consumption.

For emergency situation several solutions were planed. One of the first was the answer for the problem when pilot had not been able to relase doors before making emergency landing. In this case any damages to the fuselage should cause automatic drop of doors. The other one was reinforced construction of cockpit. It was expected that it could stand up to 50g. This value was the highest recorded during different tests simulating crashed landing. But as other tests were showing this was to much for human being. To save pilot his seat was to be fitted to special composite made shock absorbers reducing loads bellow 40g what was acceptable value.

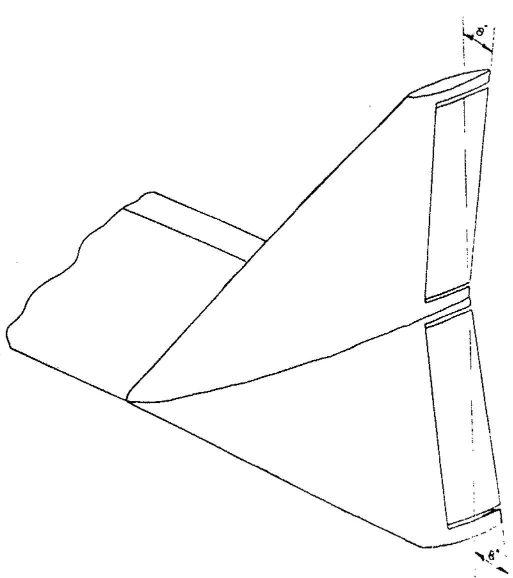


FIGURE 1 - THE CONCEPT OF WING TIP

Main wings were equipped with wing-tip fins. Their main task was to stabilize plane. The control surfaces were installed there as well. It was planned to use them for both directional control as well as for lateral. Both reactions could be achieved with deflection of the same surfaces. Solution was tested in wind tunnel for the first time in the fiveties but did not put in to prototype.

System could be operated by standard controls with mixer placed near wing tip.

The other wing related device were two LEX style surfaces. wind tunnel tests were suggesting possible increase of lift on them. At the same time both were used as a fuel tanks used during normal ag-operations. Small capacity of 200 l was absolutely satisfying for hour of independent operations. In case of any problems both tanks could be dropped like the pay load from hopper. The drop was to be initiated by the same liver but with second stage.

For short ferry flights the ferry tanks in wings were to be used. In case of long ferry flights the hopper was targeted to be a space for fuel with special non rigid tank installed inside it.

The flaps at the main wing were to be used for compensation of decrease of lift on main wing caused by dawnwash from canard. The deflection of flap was synchronized with elevator's deflection on canard. During calculation several positions of C.G. were simulated and in all cases system was working meeting expectations.

Whole structure was to be composite made. To get better material characteristics and corrosion resistance the solution with temperate fixing materials were planned to be used. The structure was to be based on the GRPs but with modern epoxy resins and manufacturing technology.

The cockpit was one of the most important places in the whole design. It was targeted like 100% modern friendly work place for human being.

Pilot was to be protected by strong structure and absorbers in the seat. Automatic seat belts should allow easy operations in cockpit and proper action in case of emergency landing.
Wentylation and aircondition system were responsible for keeping pilot comfortable during its working day despite any outside conditions.
Big windows were planned to provide visibility achieving strong Polish standards.

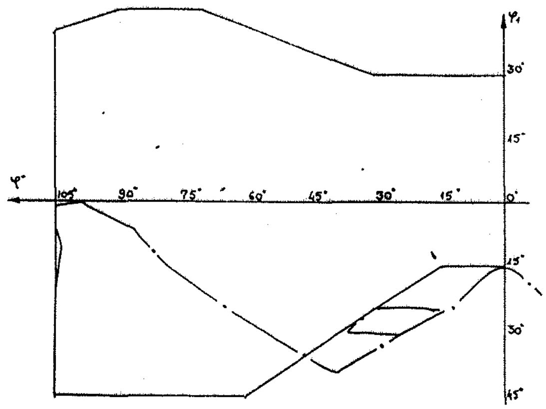


FIGURE 2 - VISIBILITY FROM COCKPIT

The agriculture systems also to be compatible with new concept. The traditional solutions with units fitted under fuselage and wings was adding to much drag. This is why the special solution with the special duct from nose to the hopper area for air transportation. It was also possible to use some pressured air from engine which during pass over field did not need full power.
In case of using solid fertilizers two nozzles behind hopper were proposed. Thanks to them it was possible to receive satisfactory distribution of fertilizers.
For liquid ones the special nozzles were to be installed on wings with transportation pipe placed inside the wing to reduce drag.
During creation of ag-equipment period drag was recognized as a secondary problem but the smooth air flow around airplane was very important as it had dramatic influence on the distribution of fertilizers.

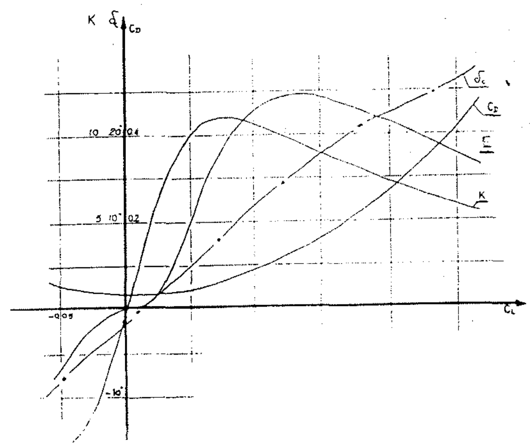
Just from the very beginning of market researches it was clear that targeted solution should lead not to only one plane. As the 1,5 m capacity was the initial volume. The market for both higher and lover figures was still uncovered.

Finally the concepts of four planes, with fives spare one, were created. The range of payload was from 600 to 3500 kg.
The lightest plane one was an answer for the special requirements for low density operations or operations over small areas. Such fields were still covered by ag-planes not only in Poland and it was sensible to have small plane as well.
In this case the radial engine M-14 with 285 kW was proposed.
The second model was able to carry 1200 - 1500 kg of water or fertilizers and it was the most flexible one. The power unit was to be a version of GTD-450 engine prepared for airplanes not helicopters developing 331 kW. This plane was competing with older types present at the market. At the domestic market such plane could replace heavier PZL-106 Kruk powered by 600 HP engine offering similar pay-load.
The capacity of 1600 was served by the plane with radial engine and this did not fit to the family and was proposed to fulfill local needs (rather political than operational or economical).
The next in line was equipped with 540 kW turboprop Walter M-601. Hopper was to have capacity of 2000 l capable for both agriculture and fire fighting operations. that model was created under trends presented by some manufacturers offering higher payloads.
The last one, the heaviest model, was to be equipped with 735 kW PZL-10 engine. This plane was targeted as a fire fighting device. Its hopper was divided into three sections, each containing 1200 l of water. Future designs from America proved positively this concept.
The commonalty was planned for structural parts between proposed models. Thanks to composite materials many molds could be used for different models. The plane with 331 kW engine was planned to be basic one. From this all future conversions were to be created.
Fuselage was the most simple to use. Wings and canards showed less flexibility and several variants would be necessary.
For future information look at the table and drawing at the end of this draft.

model [--]	1	2	3	4	5
engine type [--]	M-14	GTD-450	PZL-3S	M601	PZL-10S
engine power [kW]	258	331	441	540	735
T-O weight [kg]	1800	2460	3080	4320	5880
pay load [kg]	800	1200	1550	2500	3000
main wing [m^2]	12.7	18.9	22.8	32.0	32.0
canard [m]	5.5	5.5	11.4	16.0	16.0
fuselage [--]	A(-)	A	B	A	A(+)
main wing [--]	Mod	A	B	B	C(+)
canard [--]	A	A	B	B	C(+)

FIGURE 3 - PROPOSED MODELS AND THEIR COMMONALTY

The Cd carve is given bellow. The other carves given there are necessary deflection of elevator on canard, and aerodynamical functions K and E.



$$K = C_l / C_d$$

$$E = C_l^3 / C_d^2$$

FIGURE 4 - AERODYNAMIC CHARACTERISTICS CURVES

4. Calculations, simulations and tests.

Soon after basic concept was created for the first time problems with aerodynamical calculations appeared. Basically the subject was forcing the unconventional solutions with wortex calculation but this were still 80's and economical embargoes did not allow wider use of western hardware and software. As consequence the more conventional solutions were forced and with use of only simple computers in next period.

The aerodynamical calculations were carried on with primary target that plane had to be stable and treemed through the whole operational envelope.

All those initial dates were transferred into data file and the optimization was carried with use of simple IBM XT. Soon it was discovered that the center of gravity should be allowed to have wider margin for standard operations. The only free factor left for conversion was the coefficient of surfaces of canard and main wing. The bigger canard was the wider was CG margin. Final calculations put the design into the point were the canard was 1/3 of surface of main wing. Under those conditions plane was fully stable and manuralable inside operating envelope.

The max Cl related to main wing was around 2.6.

The other conclusion from calculations forced modifications in the fuselage arrangement. The center of gravity of payload was moved ahead of CG of full plane. This had positive influence on the load factor while doing emergency drop. Also under standard operating conditions while releasing liquid of solid fertilizers plane was decreasing angle of attack with decrease of its weight. This was limiting pilots operations to minimum.

Several ways of planes control were calculated. The most importance was put under the pitch control. The initial solution was the clean wing with elevators on the canard. The next step was coordination between canard deflection and deflection of flaps on main wing. This was causing increased drag but the drop of lift on main wing as a effect if induced velocity on main wing created by canard was minimized. Because of spare power was still available the drag was recognized as a secondary problem. Flaps on wing could not be used with full deflection because of lack of lift on canard.

This solution was giving very interesting and promising results.
The use of flaps on main wing would be also possible in case of dividing canard into three surfaced one stable and two retractable. All other solution did not allow to reach Clmax or were allowing stall on canard or on main wing if design was optimized for work conditions.
At the end the solution similar to later proposed for BAe SABA was simulated. The canard was equipped with flaps only. The longidual control were carried on by control surfaces on main wing. The dedicated ones were ailerons. Solution was offering lower Cls but planes reactions were more similar to the conventional plane.

The mass calculations were carried on without serious problems. After first step when basic formulas for preliminary designs were adopted the more advanced formulas based on the strength of material or on technological or operational requirements were used. This was giving very promising results with light, compact and strong structure. Also as it looks from the distance the fatigue problems would be solved because of low margin of tensions allowed in the structure.

The other calculated problem was the reaction of plane after stall at the canard. The results were very promising and possible loss of height was not to high as it was expected earlier and seriously lower than in case of conventional plane.

At the initials periods the idea to build flying demonstrator was created. The PZL-110 Koliber manufactured by Okecie was to be the main parts supplier. Wings and canards as well as part of fuselage and undercarriage were to be taken from this design.
Main wings were to be adopted almost without changes. The only two were wing tip correction allowing installation of winglets and modifications to the control system and main spar attachments.
Canards were to be got even simpler way. The another part of wings was to be cut in half of its span and installed on the prototype. Kolibers cockpit was to be joined in front of it by newly designed truss. This new devise was a bead for engine, canards, and hopper. Problem of engine was serious because the available PZL-Franklin used to be capricious while the radial AI-14 was much heavier and required bigger propeller what was causing additional problems to undercarriage.

Different problems of financial, economical, mental mater did not allow future development of the flying demonstrators so the other concept received its green light. It was a radio controlled model. The model was build with use of standard kit markets materials including balsa and composites.
In fact the process was started with small plane model on which the wing's sweep-back was tested. As a consequence the 10 grades were allowed instead of earlier suggested by some sources 15 grades. This fruited with simlier and lighter design proposed for final plane.

The real flying model was made in 1:3.33 scale what have 3.3 m wingspan (10 ft) and 20 kgs empty weight. The Vebra Bully single stoke engine of 50 cc was used. The propeller developed 100 N static trust (22.2 lbs).
Model had a optional space for payload later to be used for emergency drop simulations.
The internal control system was very complex to allow different configurations to be tested. At the very beginning the control system was to be "traditional". The longidual control was to be provided with use of surfaces an the canard. Yaw with standard ailerons on main wings and direction with surfaces on the winglets.
Later the ailerons were to be replaced with the opposite deflection of upper and lower surfaces at the winglets. The other solution expected to be checked during flights was a joint deflection of elevators at the canard and flaps at the main wing.
The tests of model were carried on for several months. Unfortunately most of time models spend on the ground. At the very beginning serious problems were faced with radio control system which had internal fault. Some modifications were introduced after initial ground tests proving basic concept and high stability while rolling on the ground. Also it was found that any side gust was causing change of roll direction and plane was trying to take direction against wind. This conclusion was extremely satisfactory as such solution was expected.

Finally after four months plane was taken into the air but after minute of stable flight made crash landing. The accident was caused by a failure of one of standard kit planes joints.
The canard and propeller were damaged while rest of structure remained untouched. This proved the basic concept of plane's crasworthines.
After repairing plane was flown for the second time. Meanwhile all modeller's fittings were replaced by more hopeful.
Unfortunately the second flight was not completed again and model was lost. After three minutes of stable flight it made half roll and dived hitting ground vertical from at least 50 m (150 ft).
This time the accident was caused by aileron type flatter on the port stabilizer. Its fitting was not enough strong by material failure and after fever periods of oscillations was broken.
After second crash the numerical calculations were carried on to simulate the last seconds of model's flight. For this the program prepared for calculations of aerodynamical characteristics was used and results fully proved the real reaction of model.
There were several conclusions after both accidents. First of all the rescue system with parachute should be installed. Also model's structure and control system should be optimized an looked like for model not for real plane. The were also other conclusions with less importance.
The next model which was under design was to be smaller and fully composite made and all experience collected earlier was to be introduced into new design. Unfortunately the decisions were unlucky for K-1 project and other solutions were given priority.
All program was canceled some 30 months later when State Komity for Research and Development caused any future funds for program.

Conclusions.
1. Canard configuration seemed to be still very promising for agriculture planes.
2. The high level of safety (due to stall problems) and sufficient controls might be obtained because of rather small travel of CG position possible for plane.
3. The necessary power of engine for take off and climb could execute even greater max. level speed than it would be necessary.
4. For canard configuration the ratio of max payload and max. takeoff weight could be much greater than for agriculture planes in conventional configuration.
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