SECOND EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

PAPER NO. 39

AIRCRAFT OF WIDE SPEED AND MANOEUVERING RANGE

G. Kannamüller

E. Oberdörffer

DORNIER GMBH

Friedrichshafen, Germany

September 20 - 22, 1976

Bückeburg, Federal Republic of Germany

Deutsche Gesellschaft für Luft- und Raumfahrt e.V.

Postfach 510645, D-5000 Köln, Germany

INTRODUCTION

Analysis of the expected battlefield scenario in the late eighties and nineties led Dornier to study an aircraft concept of wide speed and manoeuvering range for air-to-ground attack.

Extreme challenges are posed by the increasing effectiveness, density and variety of anti-aircraft-weapons on the battlefield and by the increasing threat by hostile counter-air and air-superiority aircraft.

Location, identification and destruction of mobile armoured targets day and night under any weather conditions add to the requirement for increased survivability.

The main design features for an aircraft to meet this challenge are:

- VTOL, at least STOL-capability
- an extremely wide speed range, including thrust supported low speed and high subsonic speed
- outstandig manoeuvrability
- improved target acquisition and stand-off combat capability

The outlined aircraft concept lends itself also to ASW missions from small ships, like frigates, improving range and reaction time and survivability compared to a helicopter.

1. TECHNICAL CONCEPT

Dornier's technical concept of an aircraft of wide speed and manoeuvering range, called LSK (Leichtes, Schwebefähiges Kampfflugzeug), shows the following characteristics:

- shrouded, single stage fan with horizontal rigid intake
- thrust vectoring by an efficient deflector system
- optimal integration of thrust deflector and wing

These characteristics are shown in Fig. 1. This concept allows to tailor the fan pressure ratio for a required mission [1].

The selection of a low fan pressure ratio leads to low required power and low fuel consumption at low speeds and hover, but to a limited high speed capability.

A high fan pressure ratio enables the aircraft to achieve high speed and specific range, but involves limited endurance in the thrust supported flight mode due to higher fuel consumption.

Fig. 2 shows the specific hovertime - that is the time the aircraft burns 1 % of its mass - over the speed potential. Reduction of fan pressure ratio is limited by increasing dimensions and weight of the shrouded fan and the whole airframe, on the other hand the state of art of single stage fans limits the pressure ratio to a maximum of 1.7. Fig. 3 indicates the trend of the relative useful load over the fan pressure ratio.

The aircraft concept relies completely on the efficiency of the thrust deflector device.

The requirements are:

- thrust vector angle more than 90^0
- thrust vectoring in hover and forward flight
- low pressure loss at any vector angle
- suitability for a high mass flow
- low weight
- suitability to create supercirculation on the wing

Fig. 4 shows four different thrust deflector systems under consideration.

The flexible cascade with a rectangular exit cross section has proved to be a promising design [2]. This design consists of several two-dimensional deflector vanes with a flexible upper and lower metal skin, a riged nose spar and movable center and trailing edge spars. The cord thickness is varied with camber (Fig. 5).

For higher fan pressure ratio a triple-slotted flap with sidewalls has shown good efficiency and reduced complexity [3] (Fig. 6).

The location of the jet relative to the wing has considerable influence on the total lift of the wing/ jet combination in forward flight. The location of the jet near the leading edge gives rise to lift reduction, while a location near the trailing edge induces an additional circulation on the wing and thus additional lift.

Fig. 6 shows jet interference for a trailing edge jet at different deflection angles [4] compared to published data for a leading edge jet (Harrier) [5]. The difference becomes sensitive at low speed manoeuvres and for STOL-performance.

2. INTEGRATION

Integration of the described concept elements into an aircraftleads to a conflict situation, the conflicting parameters being:

- propulsion system complexity
- thrust center location
- center of gravity location
- aerodynamic center location
- cockpit location and pilot's field of view

The following requirements must be satisfied:

- aerodynamic stability demands the location of the center of gravity in front of the aerodynamic center
- the equilibrium condition for all moments demands a common center of gravity and thrust center
- to ensure positive interference between jet and wing, the jet must be located near the trailing edge of the wing, that is well behind the wing AC

Four measures contribute to the solution of these problems (Fig. 7):

- forward shift of the thrust center by an additional thrust generator in the aircraft nose
- rearward shift of the aircraft aerodynamic center by increasing the horizontal tailplane volume
- rearward shift of the aerodynamic center by increasing the wing sweep
- artificial stabilitisation

An optimum solution can take advantage of a combination of these measures.

Control System

The wide speed range from hovering to high subsonic speeds and the corresponding trim margins as well as the required manoeuvrability define the control system. The control system combines momentum control for thrust supported flight and control by aerodynamic surfaces for aerodynamic flight (Fig. 8).

The pitch control can be realized by

- thrust modulation of a thrust generator in the aircraft nose
- variable thrust distribution by control nozzles at the nose and the tail of the aircraft
- deflection of the primary jet up or down at the tail

Roll

Roll control by opposite thrust modulation

- of two seperately driven fans
- of two partial jets of a central fan by variation of the exit cross sections

Yaw

Yaw control is effected by opposite swivelling of the left and right jets

Aerodynamic Control

The control in the aerodynamic supported flight is effected by conventional control surfaces. The transition from the thrust supported to the aerodynamically supported flight mode demands a continuous and steady change of authority from one control system to the other.

Propulsion System

The most important design parameter of the propulsion system is the fan pressure ratio, which has to be optimized for the design mission. Recent studies by Dornier and MTU indicated optimum pressure ratios of 1.5 to 1.7 for a close air support mission with moderate hovering time requirement [6].

The design of the propulsion system has to cater for the strong interdependence between propulsion system and pitch trim control system and aircraft configuration.

Fig. 9 gives a schematic survey of six possible arrangements.

Arrangements 1are characterized a rearward facing gas generator with a separate 0° bent air intake in the root of the vertical tailplane.

The hot gas is expanded by a free power turbine driving the fan. Exhaust gas and fan air are mixed and expelled through the main thrust deflectors. The differences are in the pitch trim and control system.

Arrangement 1.1 has a nose fan with nearly vertical axis, which is driven by a shaft and gear train from the fan. The nose fan operates only in jet supported flight. In aerodynamic flight it is separated from the main fan by disengagement of the friction clutch.

Arrangement 1.2 has a nose fan with horizontal axis, driven by shaft and gear from the main fan as before, but continuously in operation. Its jet is deflected downward in hovering flight and backward in normal flight by a third thrust deflector.

In arrangement 1.3 pitch control is effected by control nozzles expanding engine bleed air at the nose and tail of the aircraft.

Arrangements 2 are characterized by a conventional high by-pass front fan engine.

In arrangement 2.1 the fan air is expanded by the main thrust deflectors, while the engine exhaust is led to the aircraft's tail to be expanded in a combined control and propulsion nozzle.

Arrangement 2.2 differs from 2.1 in separating the core engine with fan turbine from the fan by a long shaft and engine air duct. This allows balancing a cockpit in front of the fan.

In arrangement 2.3, fan air and exhaust gas are mixed before being expelled through swivelling nozzles at the wings trailing edge. Pitch control is effected by engine bleed air and control nozzles at the extremeties of the aircraft.

Configurations

Fig. 10 shows six aircraft configurations corresponding to the six propulsion system arrangements. Note that the configurations 2 have a tail wheel landing gear arrangement owing to lack of space for a nose wheel in the fan cowl.

3. OPERATIONAL CAPABILITY

The limited scope of this paper allows only a short comment on the operational capabilities of the described aircraft concept.

Dislocation (Fig. 11)

Dornier studied a dislocation concept that combines a central operational airbase with conventional runways and all logistic facilities with dispersed sites around the base [7]. Whenever possible, the aircraft takes advantage of the runway with increased useful load. When the runways are destructed, the aircraft operates with vertial take-off and landing from the dispersed sites at limited payload. This concept keeps peacetime operational costs in known orders of magnitude and increases wartime availability considerably.

Concentration of Air Power

High cruise speed and range enable the concentration of air power on the battlefield. Studies of Dornier and the IABG showed this to be an essential advantage in comparison to low speed helicopters.

Stand-off Combat Cability (Fig. 12)

The wide speed range permits the adaption of the attack speed against a ground target to the detection range and target acquisition time. The approach speed must allow target detection, weapon lock-on, delivery and break-off without penetrating into the range of the mobile antiaircraft weapons. Field tests with helicopters proved the eye ball acquisition time of tanks to be rather long in our Central European environment. Advanced acquisition means as well as launch and forget missiles will contribute to increase the possible attack speed. Vertical landing and immediate take-off give the aircraft the capability to lurk for mobile targets when grounded in an ambush position.

High Agility

The thrust vectoring in forward flight improves air to ground and air to air combat capability and will be discussed in more detail in chapter 4.

Helicopter Escort and Pursuit

The mission of helicopter escort and pursuit seems to be increasingly promising when we consider the superior flight performance of the described concept on the one hand and the growing number of helicopters on the battlefield on the other.

Ship-based Operation

Though the example mission was cl [illegible] air support with conventional bombs and stand- [illegible] weapons, the aircraft concept seems to be very promising for operations from small ships, for example frigates. The missions could be maritime patrol, ASW and combat with air-to-surface missiles against hostile ships.

4. LSK PERFORMANCE COMPARED TO HELICOPTER AND CONVENTIONAL AIRCRAFT PERFORMANCE

4.1 Description of a Design Example

Outline requirements, Mission

Several LSK designs were made to meet the following mission requirements:

- Short take off with a payload of six cluster bombs and four anti tank missiles
- Low level cruise of 150 km
- Cluster bomb attack
- Vertical landing and lurking for 15 min with idling engine
- Vertical take off, 20 min jet supported flight including firing the anti tank missiles
- Low level cruise home
- Vertical landing

Fig. 13 shows one of the studied LSK designs reflecting two basic design objectives:

- Use of the main components of an existing high-bypass-engine
- Field of view at least as good as in a conventional aircraft

The engine is a conventional high-bypass-engine, fan and main engine being separated in longitudional direction and connected by a long shaft. By this arrangement the main engine can be put back into the rear fuselage, thus counterbalancing fan and cockpit which are situated well in front of the center of gravity. The center of gravity has to coincide with the thrust center which lies slightly aft of the main thrust deflectors. As this is far behind the wing A.C., a large and fully lifting tailplane and artificial pitch stabilisation are needed. The bypass air is expelled through the main deflectors beneath the trailing edge of the central wing, while the hot gas is expanded through a three-way nozzle which gives forward thrust in conventional flight and modulated vertical thrust in hovering flight for pitch trim and control.

Main data of this design are:

- Span	9.00 m	
- Length	14.00 m	
- Height on ground	4.33 m	
- Lifting area	25.00 m^2	(wing and tailplane)
- Operating weight empty	5700 kg	
- Design VTO-weight	8000 kg	(600 m, ISA + 15^0)
- Max TO-weight	12000 kg	(reduced load factor)

4.2 Performance

Thrust vectoring not only gives VTO capability at the appropriate weight, but also enhances STO-performance significantly. Take-off run and take-off distance over 15 m obstacle are shown in Fig. 14 for weights not allowing VTO. For comparison take-off run of an identical aircraft (equal wing and thrust loading) without thrust vectoring is indicated. Landing is always performed vertically - except in emergency situations - as at the end of a mission weight is sufficiently low. Specific range at a cruise speed of 735 km/h is between 0.6 km/kg and 0.82 km/kg, depending on aircraft weight and external stores configuration. Alpha Jet specific range is between 0.4 km/kg and 0.7 km/kg, while a typical anti-tank-helicopter specific range is about 0.75 km/kg at a speed of only 235 km/h.

Specific hovering time (time to burn 1 % of aircraft mass) is 110 s for the LSK and 450 s for the helicopter. This shows the importance of avoiding excessive hovering time with the LSK.

Thrust vectoring enhances sustained turning performance, especially in the low speed regime. Low speed turning performance is comparable to that of a helicopter when weight allows hovering (Fig. 15).

Owing to the high thrust to weight ratio, sea level specific excess power (SEP) exceeds 100 m/s, depending of course on weight and external stores. Although this is still only a fraction of the SEP of modern AS-fighters, it is about twice the SEP of subsonic CAS-aircraft. Helicopter SEP is an order of magnitude lower, although due to a different environment and highly specialized flight tactics the helicopter lives quite well with its extremely low SEP. (SEP of land vehicles is still an order of magnitude lower).

4.3. Defense and Attack Manoeuvres

In certain defensive or offensive situations rapid spilling of aircraft total energy can be of distinct advantage. Thrust vectoring in forward flight can result in extreme values of the energy loss rate or negative SEP, down to about -600 m/s. This permits strongly spiralling flight paths.

Fig. 16 shows some flight paths for different thrust deflections. The initial velocity for all flight paths is 300 m/s. Depending on flight speed and thrust deflection transient decelerations of up to - 25 m/s^2 can be expected. The normal load factor is limited to 7.33 in this example. If in a defensive situation a large thrust deflection is selected in combination with a high normal load factor, overshoot of the attacking aircraft is unavoidable and often enough the LSK subsequently acquires an offensive position.

This opinion was confirmed by an extensive air combat simulation [8]. Attacks of F-4 and F-16 type aircraft against the LSK were studied. Different combat tactics were evaluated in cooperation with GAF pilots. The simulation showed that conventional attacks are not suitable against an LSK. Besides being unsuccessful in nearly all cases, they are quite dangerous for the attacking aircraft, because in most cases the LSK can be maneuvered into a shooting position. A newly developed "Hit and Run" attack gives the attacker a slightly better chance of killing the LSK, however he still risks getting killed himself. Trying to force the LSK into hovering fails and proves to be very dangerous for the attacker. Most attacks do not even spoil the LSK-mission, be it tank-killing or conventional CAS. These results are valid for use of guns or IR-guided missiles. Possibly advanced missiles could be more of a danger for the LSK.

If the LSK is attacking ground targets, conversion probability is significantly improved by thrust deflection. As an illustrative example Fig. 17 gives the conversion boundaries for conventional bombing with and without thrust deflection. Decreased detection distance and increased detection time translate into a 20% increase of conversion probability according to preliminary study results of the IABG [2].

When an aircraft attacks armoured vehicles by guided anti-tank missiles from a distant position and is in hovering or extremely low speed flight near the ground, as the PAH will and the LSK can do, the ability to change position quickly is of vital importance. This abiliy can be measured in terms of lateral and forward acceleration (Fig. 18). These curves show quite a similar performance of PAH and LSK, especially in the first four seconds. In lateral acceleration both aircraft have to be rolled to build up a lateral thrust component. Due to higher roll acceleration the PAH performs slightly better than the LSK. Note that the LSK's lateral speed is deliberately limited to 10 m/s or 36 km/h by the flight control system. In forward acceleration the PAH has to be tilted forward, while the LSK only diminishes its thrust deflection angle, which can be done very rapidly. Therefore the LSK has the edge over the PAH. At higher flight speeds the difference becomes more and more pronounced, with LSK acceleration peaking at about 8 m/s^2 at 250 km/h, which is the maximum level speed of the PAH with no residual acceleration.

Vertical Acceleration

Positive vertical acceleration in hovering flight is directly dependent of the actual thrust-to-weight ratio. Although it can be as low as 1 m/s^2, the stability augmentation system prevents the aircraft from hitting the ground in a fast descent. Under more favorable conditions, that is low ambient air temperature, low altitude, or low aircraft weight, vertical accelerations up to 5 m/s^2 can be expected.

The engine response to thrust control inputs will be no critical factor, as starting from a high initial power setting response times will be of the order only 0.2 s.

5. SUMMARY

If we summarize the performance comparison of LSK, PAH and CAS aircraft, we come to the following conclusions:

- The LSK has essentially the same hovering performance and agility as a PAH (except for specific hovering time).
- The LSK is definitely superior to a conventional subsonic CAS-aircraft in all performance aspects.
- The LSK is able to outmanoeuvre attacking AS-aircraft, even of the F-16 class. If the attack is continued, the LSK may even shoot down the attacking aircraft.
- By virtue of its VSTOL performance the LSK can operate from dislocated sites and thus avoid counter air threat.

The LSK is a promising competitor to the advanced antitank helicopter. Its superiority concentractes on flexibility, speed, range and survivability

LITERATURE

[1] Oberdörffer, Elmar
Untersuchungen zur LSK-Auslegung:
Ermittlung des Einflusses des Gebläsedruckverhältnisses
Interner Dornier-Bericht EP10-44/72

[2] Gregor, P, et al
Auslegungsuntersuchungen für komplizierte Komponenten am LSK-Konzept:
Konstruktion, Berechnung und Bau einer inneren Umlenkschaufel für die Kaskade
ZTL-Endbericht 1974, FAG 2, Do 2.01/2
Dornier Bericht No. 74/31 B

[3] Dick, Peter
3-Spalt-Klappe, Modellmessungen an 7 Konfigurationen für 90° Strahlumlenkung
Interner Dornier Bericht BF 60-0440

[4] Thiel, Ernst, et al
Experimentelle strömungstechnische Untersuchung zur neuartigen Konfiguration eines leichten schwebefähigen Konzeptflugzeuges (LSK)
Dornier Forschungsbericht Nr. 73/26/B

[5] Barche, G, Kreuz, G.
Strahleinfluß an V/STOL-Flugzeugen im Obergangs- und Hochgeschwindigkeitsflug
Luftfahrttechnik-Raumfahrttechnik 15, Nr. 5, Mai 1969

[6] Schill, Vedova, Weiler
Triebwerksanlage für leichte, schwebefähige Kampflugzeuge (LSK)
ZTL-Endbericht 1975, FAG 1, MTU 1.14-1, MTU Bericht Nr. 75/23

[7] Conrady, Keppeler, Lowak
Vergleich der Verfügbarkeit bei disloziertem und nicht disloziertem Betrieb am Beispiel LSK
ZTL-Endbericht 1975, FAG 1, Do 1.24/2 B

[8] Foerster, Peter
Kampfwertsteigerung durch Schubunterstützung am Beispiel LSK
ZTL-Endbericht 1975, FAG 1, D 1.24/C
Dornier Bericht Nr. 75/30 B

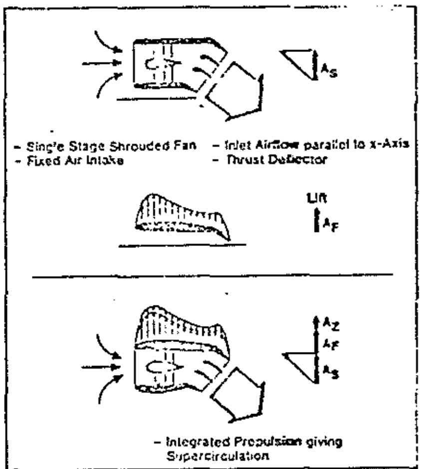

Fig.1 Concept Characteristics

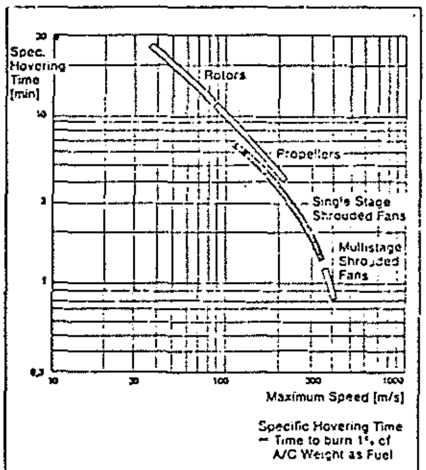

Fig.2 Specific Hovering Time

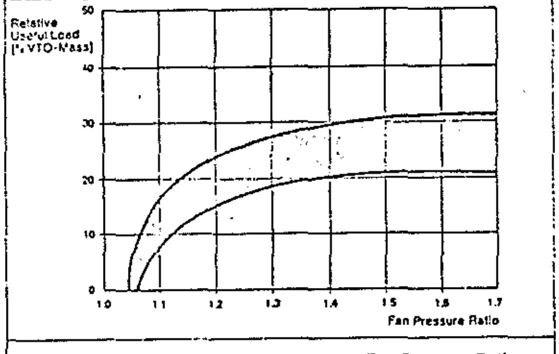

Fig.3 Relative Useful Load versus Fan Pressure Ratio

++ excellent
+ good
● acceptable
− poor
−− not acceptable

Deflector Concept / Characteristics	 Flexible Cascade	 Triple Slotted Flap	 Swivelling Nozzle	 Rotating Segments
Deflection Range	+	+	++	•
Suitability for Deflection in High Speed Flight	+	+	++	−
Thrust Losses 90°	+	•	•	•
Thrust Losses 0°	+	•	+	+
Jet Induced Effects Hovering and Transition	•	•	•	+
Jet Induced Effects High Speed	•	•	−	−
Variation of Exit Area	•	++	−	−
Suitability for Low Pressure Ratios	++	+	•	−−
Complexity	−	+	•	•
Weight	•	+	•	−
Aerolastic Behaviour	•	+	++	•

Fig.4 Thrust Deflector Comparison

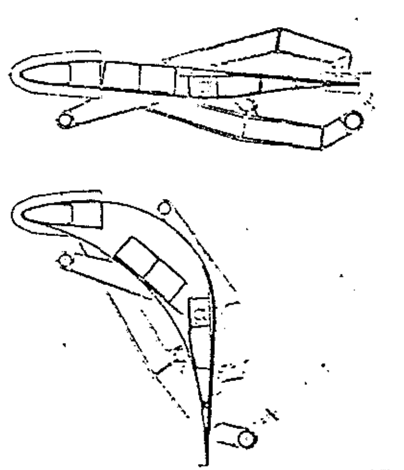

Fig.5 Flexible Deflector Vane

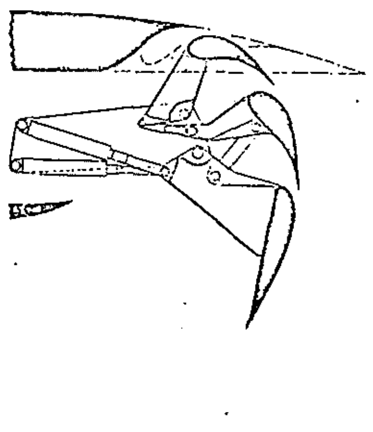

Fig.5a Triple Slotted Flap Deflector

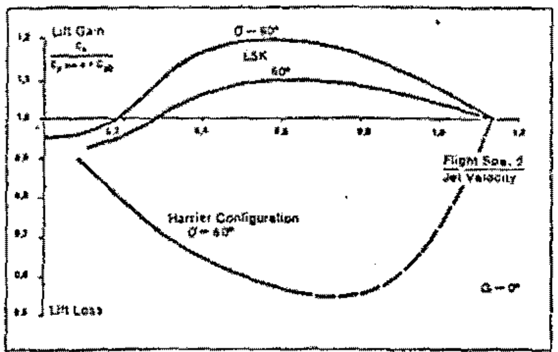

Fig.6 Jet/Wing Interference LSK – Harrier

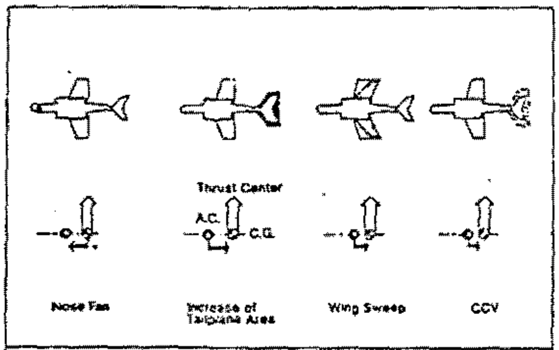

Fig.7 Centering the Centers

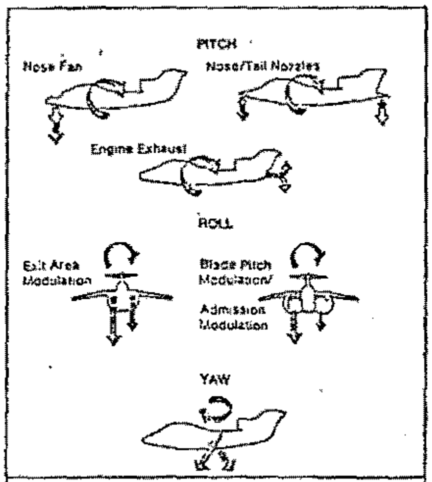

Fig.8 Control in Jet Supported Flight

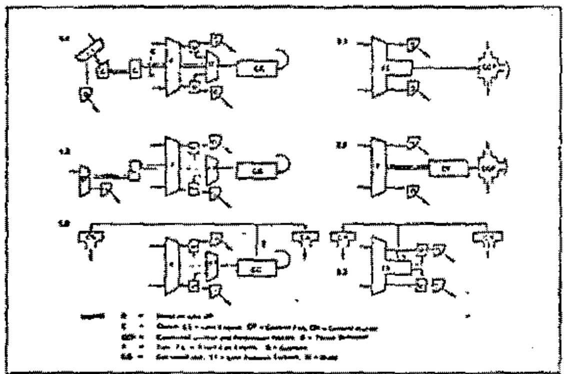

Fig.9 Propulsion System Arrangements

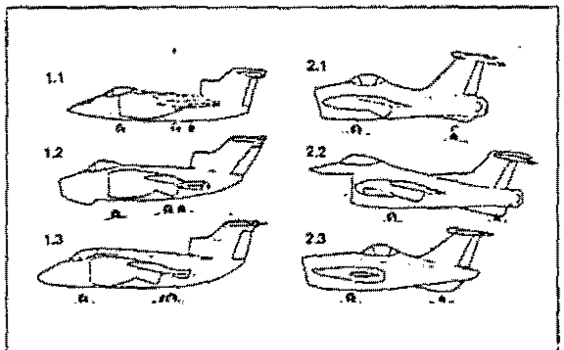

Fig.10 LSK-Configurations

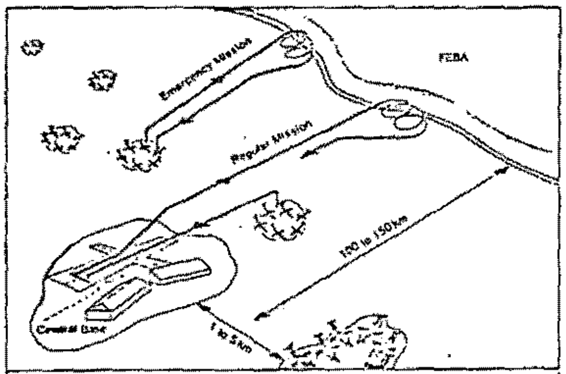

Fig.11 Dislocation Concept

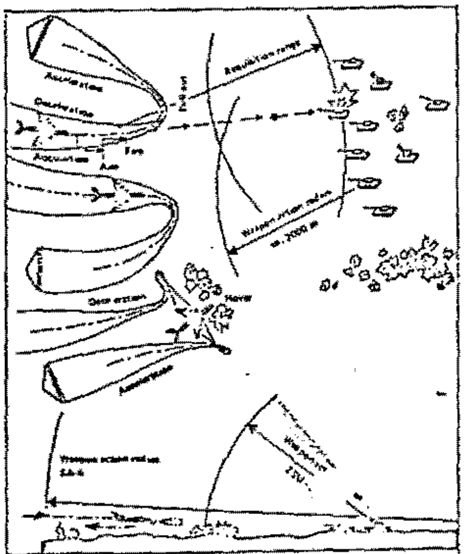

Fig.12 LSK–Tank Killing

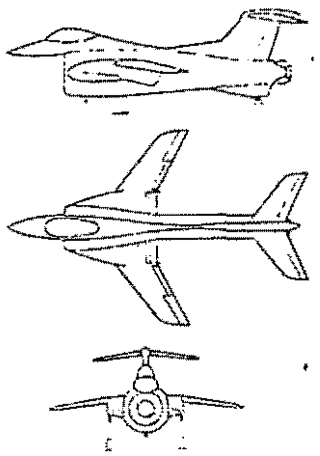

Fig.13 LSK Example Design

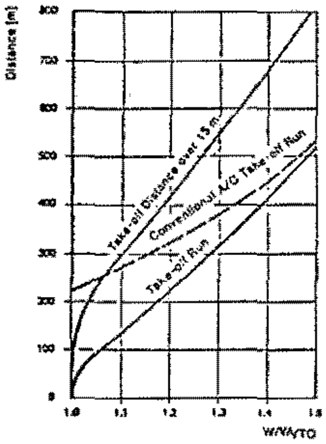

Fig.14 Short-Take-off Performance

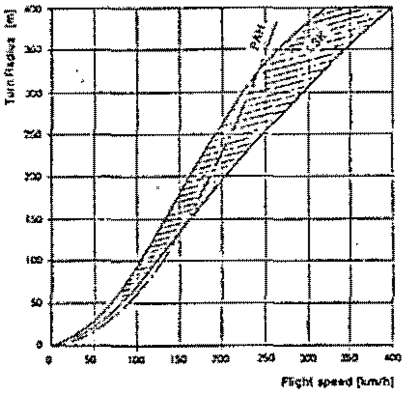

Fig.15 Sustained Turn Radius

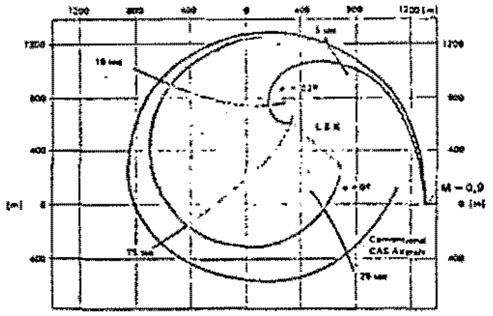

Fig.16 Flight Paths with Thrust Deflection

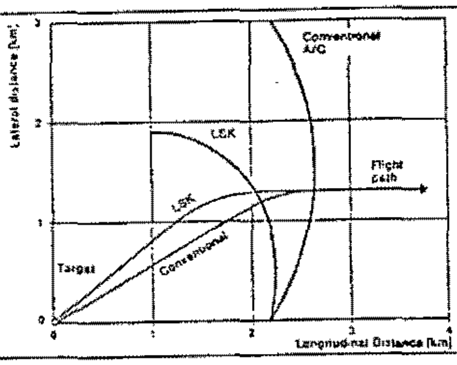

Fig.17 Typical Conversion Boundaries

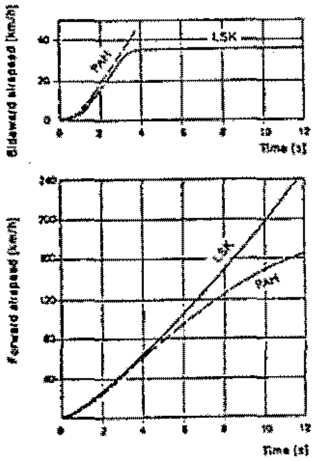

Fig.18 Lateral and Forward Acceleration (equal T/W in Hover)