Considerations in the Design of COIN Aircraft

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In a study of counterinsurgency (COIN), the specific functions required of an aircraft in the reconnaissance-strike mission are examined in detail. A set of aircraft design characteristics and requirements was established. A rating scale based upon the required functions was formulated to rate existing, developmental, and conceptual aircraft when performing a group of related COIN missions. An optimization procedure which permits the selection of the optimum aircraft and the formulation of a compatible set of requirements is presented.

Nomenclature

A = aspect ratio
AA = attack area
a = acceleration, ft/sec^2
AC = attack circle
AFPE = aircraft first pass effectiveness
ASPE = aircraft second pass effectiveness
bhp = brake horsepower
C = cost
C/E = cost effectiveness
C_L = lift coefficient
CRF = cyclic rate of fire, rounds/min
D = drag, lb
d = distance, ft
DBE = dive bombing error, ft
E = effectiveness
f = fraction, const
FPAE = first pass attack effectiveness
FR = ferry range, naut miles
g = acceleration of gravity, ft/sec^2
h = altitude, ft
K = knots
l = wavelength in sinusoidal flight, ft
L/D = lift-drag ratio
n = load factor
NG = number of guns
NR = number of rounds delivered on target
R = radius, ft, naut miles
R/C = rate of climb, ft/min
R/S = reconnaissance-strike
s = distance, ft
S = wing area, ft^2
T = time, hr
t = time, sec
TC = target circle, ft
thp = thrust horsepower
UL = useful load
V = speed, fps
VC = visual circle
W = weight, lb
W/S = wing loading, lb/ft^2
x = coordinate parallel to ground
X = pull-up distance over 50-ft obstacle, ft
z = altitude coordinate, ft
θ = flightpath inclination angle, deg
ρ = mass density, slugs/ft^3

Subscripts

a = attack
av = available
c = clearance, clearing
d = delay
des = design
f = final
i = initial
in = induced
k = knots
L = loiter
max = maximum
min = minimum
r = release
res = response
req = required
rl = resolution
t = turning
tg = target
to = takeoff
tr = transit
v = visual
xs = surplus
50 = over 50-ft obstacle
0, 1, 2 = response time

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Introduction

A STUDY of the effectiveness of airborne systems in counterinsurgency has been conducted.[1] This six-volume study was comprehensive and considered many factors of the total problem. This paper describes only the general analysis of aircraft system requirements imposed by COIN, and design implications resulting. New concepts not included in Ref. 1 are reported for the first time.

Aircraft System Requirements

Reference 1 selected six countries for detailed study of geography, weather, and other factors pertinent to COIN operations to obtain data for analysis. These countries were widely separated longitudinally, but had warm climates. The selection was made to obtain a variety of factors likely to influence COIN, and not because of any likelihood of being involved in COIN operations. It was shown that the most difficult mission, although not the most prevalent in COIN, was reconnaissance-strike (R/S), and that if an aircraft could perform R/S satisfactorily, it could perform other required missions adequately. In order to accomplish the mission and functions required, it was necessary to determine in a quantitative manner realistic system requirements peculiar to COIN. This was done by outlining the sequence of necessary functions to be accomplished in the R/S operation, and, in Ref. 1, which also served as a model with which to rate the aircraft. If an aircraft could not accomplish a

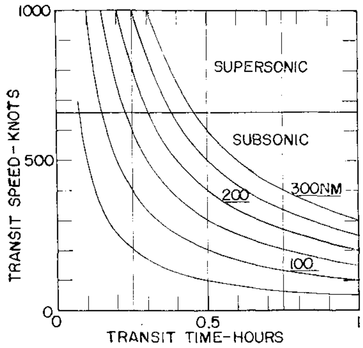

Fig. 1 Aircraft transit speed required for various target distances as a function of transit time for a 1-hr reaction time.

function, it could not complete the mission, or would it rate low. The functions and the factors upon which they depend are discussed briefly in the following.

1. Transport of Aircraft to the Country of Use

If the aircraft is to be flown to the country of use, it must be able to fly the longest intermediate stage with necessary equipment for immediate deployment. Although not absolutely necessary, if ferry range is achievable without detriment to other functions, the aircraft would have increased versatility, as it could go into action immediately without going through an assembly or demothing depot.

2. Operational Readiness

The aircraft must be operationally ready when needed. The low skill levels and premium on spare parts existing in forward COIN areas dictate a simple, rugged, reliable aircraft capable of easy, simple field maintenance, and short turn-around time without special loading or service equipment.

3. Takeoff from Runways

The aircraft must be capable of using existing or temporary runways in the COIN countries. These vary from short, unimproved wet sod to 10,000-ft all-weather runways with complete facilities. There are a surprisingly large number of runways of 3000-ft equivalent sea-level length or longer existing in all countries of the world. Six countries were selected to obtain representative data. For comparison, all runways were reduced to an equivalent sea-level length by multiplying the length by the square of the density ratio corresponding to a hot day at the runway altitude. This study assumed utilization of a few main bases located at the major runways with a widespread deployment of small numbers of aircraft to temporary bases surrounding current insurgent activity, and supported by the COIN aircraft itself. Most military operations could be conducted from the major bases, if time and distance were not critical, but in periods of high insurgent activity, which usually last less than 1 hr, dispersed bases would be needed near the local areas. STOL characteristics, requiring at least an equivalent sea-level distance over a 50-ft obstacle of 750 ft off wet sod, would be required only for civic actions in remote areas where runways must be hacked out of the jungle, and in combat zones where landings must be made in small clearings on rough ground to off-load troops, supplies, or evacuate wounded. The majority of military operations could be conducted off runways of 3000-ft equivalent sea-level length. Because of possible loss of an engine in remote or combat areas, a single-engine takeoff capability up to 10,000-ft altitude is desired. This is a severe requirement and implies an aircraft of high-performance potential and powerful controls.

4. Reliability, Handling, and Safety

The aircraft must be able to operate safely and reliably until the mission is completed. This requires a rugged design with good stability and control characteristics under all conditions of loading and power from low-speed loiter to high-speed dive. Good navigation and communications systems for all weather are required. To fly low at night, and in and out of valleys requires a minimum acceptable equivalent sea-level rate of climb of 5000 ft/min and minimum acceptable maximum climb angles of at least 15°. Because of visual restrictions, a radius of turn of less than 750 ft is required, and, in addition, excellent maneuverability, excellent single-engine operation and ceiling of at least 15,000 ft, and ground level ejection seats are also required.

5. Survivability

This study assumed that, in COIN, no air opposition would be encountered, nor any large caliber directed antiaircraft guns or missiles, but that small arms ground fire was the major threat. Good survivability can be achieved by designing to have low detectability, good maneuverability, and low vulnerability. Very quiet propellers can be designed using low rpm and large diameter which will produce high efficiencies and a noise level of only 65 db at 500 ft below them.[2–4] Low infrared radiation can be designed to negate the utility of simple IR detectors. Covert actions require both of these characteristics. Good survivability implies some redundancy, use of armor plate, use of structures as shields, placement of critical equipment in shielded areas, and low vulnerable cross sections.

6. Allowable Reaction Time and Transit Speed

The allowable reaction time is the allowable time in which the aircraft must complete its attack in order to achieve a defined threshold of effectiveness. This time must not exceed the aircraft transit time to the target plus any prior delay due to communications, decision channels, or aircraft alert. The minimum allowable speed is $V_{tr} = R/(T_r - T_a)$, and the allowable transit time is $T_{tr} = R/V_{tr}$, where R is range, T_r is the reaction time, and T_d is the delay time. Typical guerrilla skirmishes requiring aircraft support last 45 min to an hour. Protracted engagements seldom occur until a low level of limited war is reached. The V_{tr} for various ranges is plotted in Fig. 1 vs T_{tr} for $T_r = 1$ hr. As T_d approaches T_r, excessive V_{tr} are required for all ranges, and may require supersonic aircraft. From mission radius studies, a radius of 250 naut miles would be adequate for most countries in the world, and if $T_d = \frac{1}{2}$ hr, $V_{tr} \geq 500K$. These speeds are not compatible with a simple light airplane, but are reasonably consistent with STOL aircraft. Acceptable V_{tr} can be obtained by reduction of T_d by good communications, shortening R by dispersal bases, airborne alert, or patrol in insurgency areas. The presence of aircraft in an area suppresses insurgency, and long-endurance, low-speed aircraft on patrol and capable of R/S may remove the necessity for high V_{tr}.

7. Mission Radius

The mission radius was determined from the range necessary to reach potential target areas, to perform the required action, and to return to base. For the six countries studied, a computer model was used to calculate the total percentage of the country lying within a specified distance from at least a given number of airfields with runways of a given length. In two of the countries, large areas of sparse population were found. Since insurgency actions occur near population centers, the calculation for these two countries was made for that portion of the country containing a fixed percentage of the population. In the sample set given, 90% of the country or populated area containing at least 90% of the population laid within the indicated distance of at least two airfields having equivalent sea-level lengths of at least 3000 ft. Also given (Table 1) is V_{tr} for $T_r = 1$ hr and $T_d = \frac{1}{2}$ hr.

The distance varies with size, terrain, climate, and type of internal transportation system such as roads, rails, or rivers, all of which determine population centers. From information of this type, the mission radius was chosen. For the sample set, 250-naut miles mission radius would cover all countries. In three countries, $V_{tr} \geq 150K$ would permit $T_d = \frac{1}{2}$ hr for $T_r = 1$ hr; two would require $V_{tr} \geq 340K$, and one $V_{tr} \geq 470K$. Low speeds are compatible with high search and loiter effectiveness, so that low V_{tr} are desirable. The need for intermediate airfields, airborne alert, or patrol in some countries is evident.

8. Loiter Time and Speed

Given arrival at the target area within allowable T_r, the aircraft must have sufficient loiter capability at the low speeds imposed by the sensor effectiveness to be able to search for the activity, or the insurgents if they break off contact and leave the area. Each 15-min delay in reaching the target area increases the radius of the circle by 1 mile, in which the insurgents may be found. The loiter time must be sufficient to make a search of the probable area. In the presence of aircraft, insurgents hide, but if the aircraft remains in the area from 15 to 20 min, it is invariably fired upon, even by well-disciplined troops. It is one of the surest methods of locating insurgents. The loiter time and speed was set for this study for the R/S operation by optimizing the useful load among loiter fuel, sensors, and weapons to maximize the mission effectiveness. Loiter times exceeding an hour are required to obtain high effectiveness.

9. Target Detection and Identification

Currently, target detection and identification is the most serious technological COIN limitation, and is the limiting function of the success of the R/S operation. Every effort should be made to increase the aircraft system sensor capability and provisions for the installation of a multiplicity of sensors, and to provide the most favorable visibility for the crew and sensors. There should be a crew of at least two, to enable one to act as observer and to operate the sensors, to share flying duties on long missions, to act as pilot if needed, and to permit training of indigenous personnel. Because of sensors, one of the critical design requirements is for economical flight at low speeds and long times to allow time for target identification. With good contrast, the normal human eye can resolve two objects when they subtend $1\frac{1}{2}$ min of arc and can identify an erect man when he subtends 14 min of arc. Assuming a man is 18 in. wide and 5 ft tall, he could be resolved from the background as an object and a possible target at $R_{rl} = 1200$ yd, and identified as an erect man at $R_v = 400$ yd. If crouching or only partially visible, R_v would be shortened proportional to the visible height. Poor contrast, low illumination, and camouflage, especially that which breaks the contours, seriously reduce R_v.

At 500-ft altitude, a strip of ground 2182 ft wide would contain targets that could be identified, if properly oriented. At $100K$, there would be 49,131 prone man-sized target locations or 22,519 erect man-sized target locations to be scanned each second. A trained eye in a slow pursuit and search scan may identify a target by form with foveal vision, and in the peripheral vision by motion, contrast, and convexity. Even at $60K$, the pilot has difficulty searching and simultaneously maintaining orientation of the aircraft. As speed increases, he narrows down his width of scan until at high speed he looks almost directly ahead. A pilot looking forward and two observers, one covering each side of the aircraft, is a good arrangement to search the target identification area. This sharing of tasks improves the likelihood of target identification, but presents problems of getting usable information to the pilot. As speed increases, identification ability decreases rapidly.

Table 1 Distance from any point in six countries to at least two airfields with runways at least an equivalent sea-level length of 3000 ft

Country	1	2	3	4	5	6
Distance, naut miles	170	50	73	160	235	58
V_{tr} for $T_r = 1$ hr, and $T_d = \frac{1}{2}$ hr, K	340	100	146	320	470	116

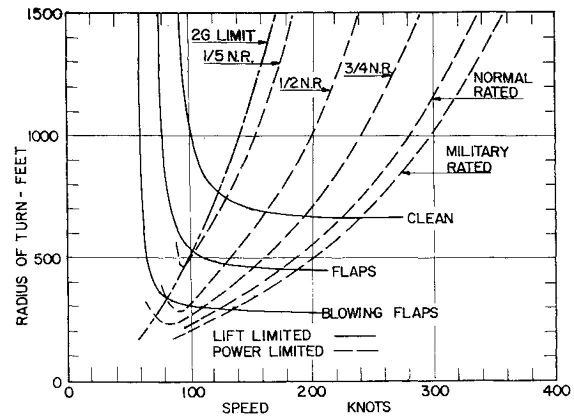

Fig. 2 Radius of turn as a function of flight speed for three lift configuration, five power levels, and a 2g limit.

Sensors can aid or improve the detection ability of the eye by improving the illumination, contrast, and background, but usually at reduced width of field. Some sensors use a blip on the screen, with no background clutter, and therefore make possible detection easier. One of the problems is how to transmit this information to the pilot in usable form for the R/S mission. Rain, fog, dust, darkness, and foliage greatly reduce or negate the effectiveness of sensors. Benefit can be derived from multiple sensors, but at the expense of weight, complexity, and cost. It was assumed in this study that visual recognition and identification of targets, including TV and IR, was the main source of target identification. Other means were studied, but for a simple lightweight aircraft, they did not appear feasible.

10. Radius of Turn

The maximum value of the allowable radius of turn R_t was established from the requirement that the pilot be able to keep the target within R_v while maneuvering to attack. Since the slant range cannot exceed 1200 ft for a 5-ft man, $R_t \leq [1200^2 - h^2]^{1/2}$ establishes R_t for both sensors and human eye for each altitude. Most operations would be conducted 50 ft $< h \leq 500$ ft, which requires $R_t \leq 1091$ ft. The pilot must keep the target within R_v and the load factor n, for both pilot and observers, within human tolerance through the turn. In general, R_t may be expressed as $R_t = V^2/g[n^2 - 1]^{1/2}$, but R_t may be limited by $C_{L\max}$ or the thrust horsepower available thp_{av}. When $C_{L\max}$ limited,

$$R_t = 2W/C_{L\max}g\rho S[1 - (V_{\text{stall}}/V)^4]^{1/2} \tag{1}$$

and when thp limited,

$$R_t = (V^2/g)[\text{thp}_{in}/\text{thp}_{xs}]^{1/2} \tag{2}$$

The $R_{t\min}$ for a given thp occurs at that V at which these two expressions are equal. R_t as a function of V for $C_{L\max}$, thp limited, and $2g$ limited turns are shown in Fig. 2 for three different lift configurations and five different thp_{av}. At the low V imposed by the sensors, R_t is usually $C_{L\max}$ limited. High lift devices can reduce R_t and the V at which it occurs, if thp is available, as shown in Fig. 2. For a

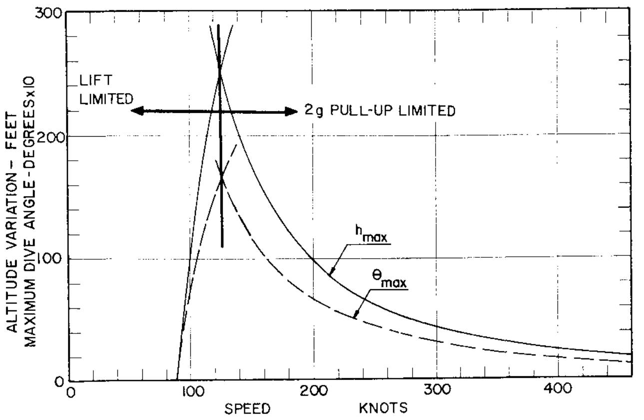

Fig. 3 Allowable altitude variation and maximum flightpath angle as a function of flight speed, when flying a sinusoidal flightpath for lift limited and 2*g* limited flight.

given lift configuration, increasing thp_{av} reduces R_t only slightly above a given level of thp_{av}, and then results in large n, since $n = [thp_{xs}/thp_{in}]^{1/2}$. R_t may be limited by n, either because of crew or structural causes. The limit line for $n = 2$ has been added in Fig. 2 to show the upper limit of human tolerance using scopes. It is observed that for the given aircraft, $R_{t_{min}}$ occurs at lower V than that for $n = 2$ for all lift configurations, and this R_t is considerably less than R_v.

11. Search Mode and Flightpath

Since the aircraft will be searching for men, it must fly low enough to maintain visual contact and slowly enough to allow time for target identification. It must follow the terrain, and, if rolling hills, the aircraft must fly an undulating flightpath, dipping down into valleys and rising over ridges. It must be determined what altitude variation h and load factor n is possible and tolerated as a function of V. To assess this problem, the flightpath was assumed to be sinusoidal with an amplitude $(h/2)$ and a distance between crests of l, so that $Z = (h/2)[1 - \cos(2\pi x/l)]$. The radius of curvature at any point along the flightpath is associated with the normal acceleration by

$$R = V^2/g(n-1) = \{1 + [(\pi h/l)\sin(2\pi x/l)]^2\}^{3/2}/(2\pi/l)^2\,(h/2)\cos(2\pi x/l) \quad (3)$$

The R_{min} occurs at the crests and troughs as $R_{min} = (l/2\pi)^2(2/h) = 2nW/g\rho S C_{L_{max}}(n-1)$, and the amplitude becomes, when n limited

$$(h/2) = g(n-1)(l/2\pi V)^2 \quad (4a)$$

and when $C_{L\max}$ limited

$$(h/2) = (n-1)(l/2\pi V^2)g\rho S C_{L_{max}}/nW \quad (4b)$$

and

$$\tan\theta_{max} = \pi h/l \quad (5)$$

Figure 3 shows the allowable variation in altitude h and the maximum angle of dive or climb θ_{max} on the flightpath as a function of V for a typical aircraft with $l = \frac{1}{2}$ mile. At low V, h and θ_{max} are limited by $C_{L_{max}}$, and at high V by a $1g$ normal acceleration which gives $n = 2$ at the trough and $n = 0$ at the crest. The fore and aft maximum accelerations are $a_{max} = g \sin\theta_{max}$. High normal accelerations cannot be tolerated by the crew for any length of time, especially if using scopes, and oscillating longitudinal accelerations hamper both flying and observing. This flightpath is very similar to that for Phugoid motion and may be difficult to fly or cause stability problems.[5] It is seen that as V increases, h and θ_{max} increase rapidly from V_{stall}, reach a maximum when lift limit and n limit are equal, and then reduce rapidly at const n as V increases, becoming negligible at high speed. θ_{max} is important in determining the limiting capability of the aircraft to dive toward the target. Low W/S, high n, and high lift devices increase h and θ_{max}, and are design variables important to terrain following.

12. Attack Effectiveness

To be effective, the aircraft must be able to attack targets on the first or subsequent pass without losing visual contact with any targets located and identified. The aircraft first pass effectiveness (AFPE) is defined as the ratio of the area in a visual quadrant which the aircraft can maneuver to attack to the area of the visual quadrant. In maneuvering, it is assumed that after a target is identified, the aircraft turns at const V toward the target, and during the time t, rolls out and travels in a straight line the distance Vt while stabilizing and sighting, and then attacks. If guns are used, a terminal distance must be allowed to break off contact. Bombs, such as parafrag bombs, guns, grenades, and rockets may be delivered either horizontally or in a dive. The attack radius R_a is defined in Fig. 4, and is the vector sum of R_t and Vt. The area between the attack circle and R_v is the attack area AA and the ratio of this area to the area of the visual quadrant is the AFPE. At low V, R_a is limited by $C_{L_{max}}$, and at higher V by either the allowable n or thp_{av} in the turn. This is shown in Fig. 5 for three lift configurations. The AFPE may

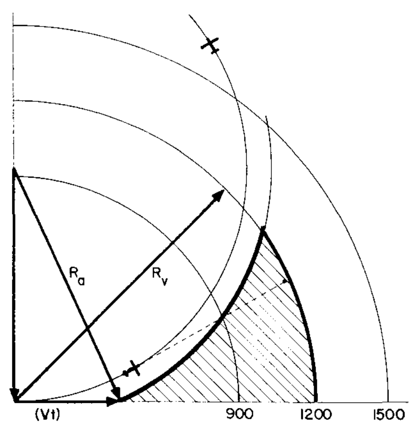

Fig. 4 Attack area defined by visual radius, turning radius, and sighting time, and attack radius.

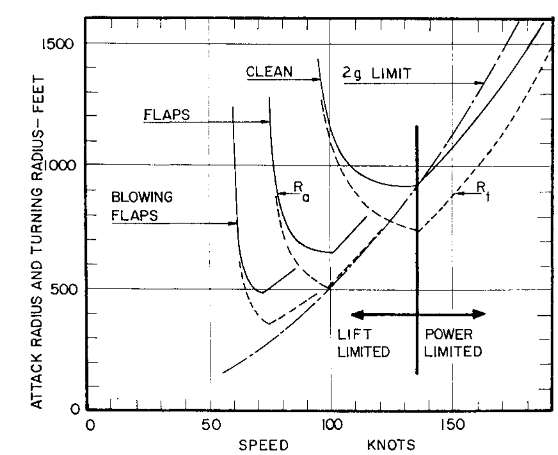

Fig. 5 Attack radius and turning radius as a function of flight speed for three lift configurations in the lift limited, power limited, and 2*g* limited flight.

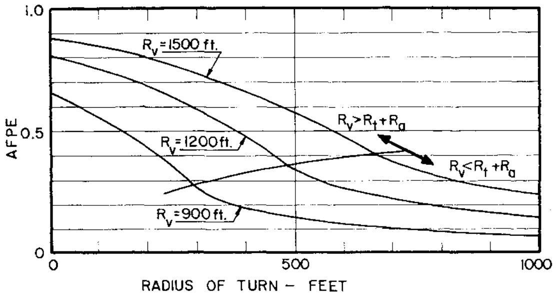

Fig. 6 Aircraft first pass effectiveness at 125*K* for three visual radii as a function of radius of turn.

be calculated from

$$AFPE = [1 - 2(R_a/R_v)^2\{1 - (2/\pi)\sin^{-1}(Vt/R_a)\} - 2R_tVt/\pi R_v^2] \qquad R_v \geq R_a + R_t \qquad (6)$$

or

$$AFPE = (2/\pi)[(R_t/R_v)[1 - |\{1 - (Vt/R_v)^2\}R_v/2R_t|^2]^{1/2} - R_tVt/R_v^2 + \sin^{-1}[\{1 - (Vt/R_v)^2\}R_v/2R_t] + (R_a/R_v)^2[\sin^{-1}(\{1 - (Vt/R_v)^2 - 2(R_t/R_v)^2\} \times R_v^2/2R_tR_a) + \sin^{-1}(R_t/R_a)]]$$
$$R_v \leq R_a + R_t \qquad (7)$$

The AFPE for three different R_v is shown in Fig. 6 as a function of R_t for $V_k = 125K$ and $t = 2.5$ sec. $R_v = 900$ ft corresponds to the R_v for a 3-ft, 9-in. pygmy, $R_v = 1200$ ft to a 5-ft man, and $R_v = 1500$ ft to a 6-ft, 3-in. man. When political considerations require positive identification, $R_v \leq 900$ ft must be used with a much lower effectiveness, but if positive identification is not required, $R_v \geq 1500$ ft may be used. When $R_v = 2R_t$, the aircraft can just turn back for a second pass without losing sight of the target. When $R_v = R_a + R_t$, R_a is just tangent to R_v at 90°, and marks a boundary for the attack circle lying inside R_v. For $R_v > R_a + R_t$, the AFPE increases rapidly. At $R_t = 0$, the limiting condition for a helicopter is reached. It is seen that small R_t is desired for good AFPE, and this implies low W/S, high n, and high $C_{L_{\max}}$ and high lift devices. From Figs. 2–5, it is seen that high V reduces AFPE drastically, whereas low V and high lift devices reduce R_t and greatly improve AFPE. The effect of V on AFPE is shown in Fig. 7 for a typical aircraft, using R_t and R_a from Fig. 5 at corresponding V. The advantage of high lift devices is apparent.

To assess the influence of the man on AFPE, the following model, based on known characteristics, was used. Assuming a constant scan rate, and that the efficiency of scan, above a threshold $V_k = 60K$, is inversely proportional to the area to be scanned, and hence V, the influence of the man and sensors is calculated as the product of the AFPE at a given V by the ratio of $60K/V_k$ to obtain in Fig. 7 the dotted curves which are the combined effectiveness of the aircraft-man-sensor, and is called the first pass attack effectiveness (FPAE). The advantage of low V and high lift devices is again apparent, as is the need to improve sensor capability.

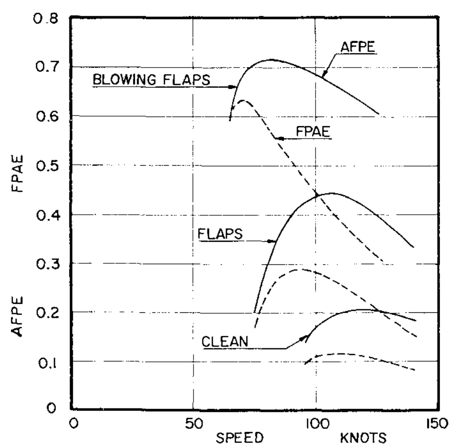

Fig. 7 Aircraft first pass effectiveness and first pass attack effectiveness for three lift configurations as function of flight speed.

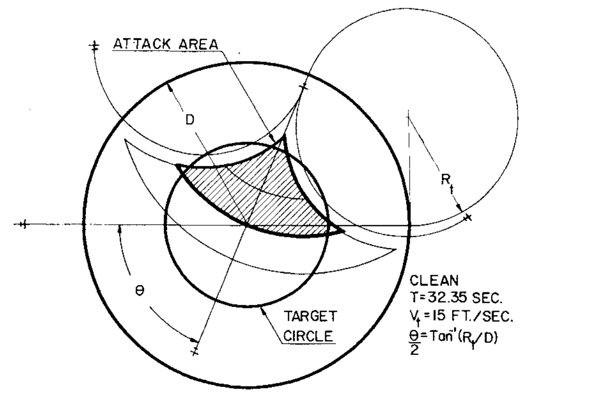

Fig. 8 Aircraft second pass effectiveness for the clean airplane.

Many targets cannot be attacked on the first pass either because of their location being inside the attack circle or late identification. A second pass is required to attack the target. The aircraft second pass effectiveness (ASPE) can be evaluated if prescribed conditions are used. The problem is complicated if the target can move. The following model was used to evaluate the ASPE. A ½-mile-diam circular clearing in a jungle was assumed with the target at the center. The aircraft flies over the target which does not move until the aircraft passes it. (In COIN situations, personnel do not move until the aircraft passes, or they believe they have been detected, or they have been attacked.) The aircraft continues on a straight line to the edge of the clearing, and turns at const V. (To obtain the maximum, it changes V to start the turn at the R_t to maximize the FPAE for the lift configuration.) It turns until it again reaches the edge of the clearing, rolls out, and flies toward the center of the clearing as shown in Fig. 8. When R_v coincides with the original target location, the ASPE is evaluated. The target is assumed to move radially in any direction at a constant speed V_{tg} from its original location during the time T_a in which the aircraft is maneuvering to attack, and is located within the target circle (TC) of radius $V_{tg}T_a$. The ASPE is defined as the ratio of that portion of the TC which lies within the first pass attack area to the area of the TC. This definition permits an ASPE to be evaluated. The aircraft may turn right or left after the evaluation point to attack targets, and

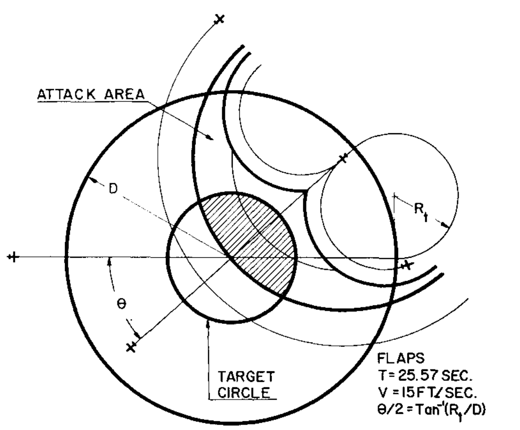

Fig. 9 Aircraft second pass effectiveness with flaps.

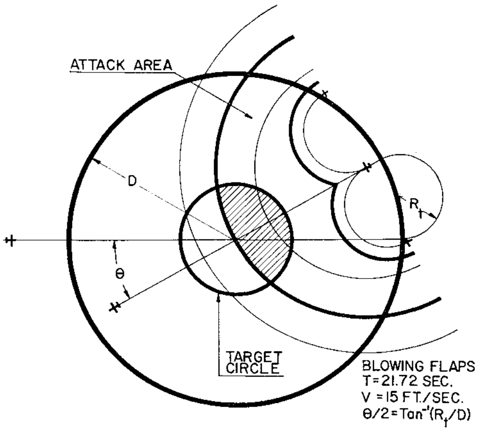

Fig. 10 Aircraft second pass effectiveness with blowing flaps.

may have a much higher effectiveness. Figures 8–10 illustrate evaluation of the ASPE for an aircraft with three lift configurations. It was assumed that $V_{tg} = 15$ fps, which is as fast as a man encumbered by weapons and military gear can run. The advantages of high lift devices and low attack V is apparent, but this must be traded off with the survivability of the aircraft and its fire power. The influence of R_v is obvious.

The ASPE can be calculated from the following for no double value regions. Case I, target circle intersects attack circle twice within the visual circle:

$$\text{ASPE} = [(R_v/R_{TC})^2 + 1]/2 + [2R_t(x_2 - x_3) - (R_v - x_3)\{R_{TC}^2 - (R_v - x_3)^2\}^{1/2} + x_2\{R_a^2 - x_2^2\}^{1/2} + x_3\{R_a^2 - x_3^2\}^{1/2} - x_1\{R_v^2 - x_1^2\}^{1/2} - (R_v - x_1)\{R_{TC}^2 - (R_v - x_1)^2\}^{1/2} + (R_v - x_2) \times \{R_{TC}^2 - (R_v - x_2)^2\}^{1/2} - R_v^2 \sin^{-1}x_1/R_v - R_a^2\{\sin^{-1}x_2/R_a - \sin^{-1}x_3/R_a\} - R_{TC}^2\{\sin^{-1}(R_v - x_1)/R_{TC} - \sin^{-1}(R_v - x_2)/R_{TC} + \sin^{-1}(R_v - x_3)R_{TC}\}]/\pi R_{TC}^2$$

$$x_2, x_3 < x_1 \qquad x_4 > x_6 \qquad (8a)$$

Case II, target circle intersects attack circle once within visual circle:

$$\text{ASPE} = [(R_v/R_{TC})^2 + 1]/2 + [2R_t(x_5 - x_3) - (R_v - x_3)\{R_{TC}^2 - (R_v - x_3)^2\}^{1/2} - x_5\{R_a^2 - x_5^2\}^{1/2} + x_3\{R_a - x_3^2\}^{1/2} - x_5\{R_v^2 - x_5^2\}^{1/2} - R_{TC}^2 \sin^{-1}(R_v - x_3)/R_{TC} - R_v^2 \sin^{-1}x_5/R_v - R_a^2\{\sin^{-1}x_5/R_2 - \sin^{-1}x_3/R_a\}]/\pi R^2_{TC}$$

$$x_2 > x_1 > x_3 \qquad x_4 > x_6 \qquad (8b)$$

Case III, target circle lies entirely within attack area within visual circle:

$$\text{ASPE} = [(R_v/R_{TC})^2 + 1]/2 + [x_1\{R_v^2 - x_1^2\}^{1/2} - (R_v - x_1)\{R_{TC}^2 - (R_v - x_1)^2\}^{1/2} - R_{TC}^2 \sin^{-1}(R_v - x_1)/R_{TC} - R_v^2 \sin^{-1}x_1/R_v]/\pi R_{TC}^2$$

$$x_1 > x_4 > x_6 \qquad x_2, x_3 \text{ imaginary} \qquad (8c)$$

Case IV, attack area lies entirely within target circle within visual circle:

$$\text{ASPE} = (R_v/R_{TC})^2/2 + [2R_t(x_5 - x_6) - x_5\{R_a^2 - x_5^2\}^{1/2} + x_6\{R_a^2 - x_6^2\}^{1/2} - x_5\{R_v^2 - x_5^2\}^{1/2} - R_v^2 \sin^{-1}x_5/R_v - R_a^2\{\sin^{-1}x_5/R_a - \sin^{-1}x_6/R_a\}]/\pi R_{TC}^2 \qquad (8d)$$

where $x_5 > x_6 > (R_6 - R_{TC})$, R_c is the radius of the clearing;

$$R_{TC} = V_{tg}\{(2R_c - R_v) + R_t[\pi + 2\tan^{-1}R_t/R_c]\}/V$$

$$x_1 = (2R_v^2 - R_{TC}^2)/2R_v$$

$$x_{2,3} = R_v(R_v^2 + R_a^2 + R_t^2 - R_{TC}^2)/2(R_v^2 + R_t^2) \pm [\{R_v(R_v^2 + R_a^2 + R_t^2 - R_{TC}^2)/2(R_v^2 + R_t^2)\}^2 - \{(R_v^2 + R_a^2 - R_t^2 - R_{TC}^2)^2 + 4R_t^2(R_v^2 - R_{TC}^2)\}/4(R_v^2 + R_t^2)]^{1/2}$$

$$x_4 = R_v - R_{TC}$$

$$x_5 = (R_v^2 - \{[R_v^2 - (V_t)^2]/2R_t\}^2)^{1/2}$$

$$x_6 = Vt$$

The ASPE was evaluated as a function of V for a typical COIN aircraft for three lift configurations, and is shown in Fig. 11. The ASPE may be lift limited or n limited; the n limited curve is the same for all lift configurations, whereas the lift limited curve shifts to lower V and has a slightly higher asymtotic value as $C_{L_{max}}$ is increased by high lift devices. The ASPE is zero at V_{stall} as $R_t = \infty$, and the aircraft cannot turn back for a second pass. As V increases, R_t and R_{TC} decrease rapidly, causing a rapid increase in ASPE, even though the attack area, (AA) lies entirely within the target circle (TC). As V increases in the vicinity of the knee of the lift limited curve, first one and then two intersections of the attack circle (AC) and the TC occur within the visual circle (VC). As V is increased further, R_t and R_{TC} both approach an asymtotic limit and AA lies entirely within TC and n increases rapidly. AA decreases as V increases, and slowly increases ASPE until at $Vt = Rv$, ASPE = 0.5. At much lower V, an n limit is imposed either by the crew or structures.

In Fig. 11, a personnel limit of $n = 2$ is shown. For n limit, the ASPE is greatest at the lowest speed at which $n = 2$ can be achieved for the configuration. The TC lies entirely within AA, but as V increases R_t and R_{TC} increase rapidly while AA is decreasing slowly. Near the knee of the n limit curve, two and then one intersection of AC and TC within VC occurs. Further increase of V causes rapid decrease of ASPE as R_t and R_{TC} increase rapidly, and AA now lies wholly within TC. ASPE = 0 at $R_v = Vt$ where AA = 0.

Figure 11 shows that high ASPE occurs within a narrow speed range for a given lift configuration and decreases rapidly for V outside this range as R_t and R_{TC} increase rapidly. Since R_t is small at low values of (W/S) and large $C_{L_{max}}$, high lift devices and low wing loadings are mandatory for good ASPE. High lift devices widen the speed range for a given value of the ASPE, and at a given speed yield higher

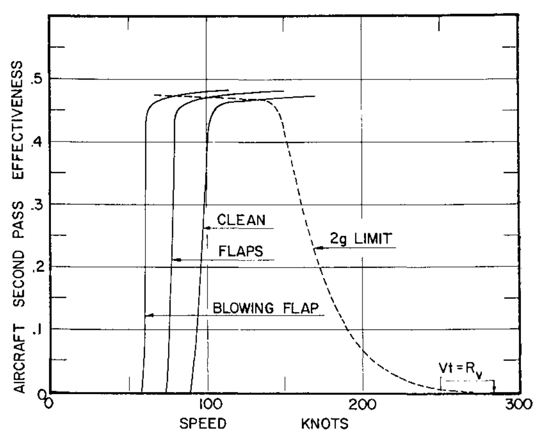

Fig. 11 Aircraft second pass effectiveness as a function of speed.

values of the ASPE. High lift devices permit lower speeds to be used in the second pass, and there is no advantage to increasing the speed in the second pass if n limited.

If the aircraft goes beyond the edge of the clearing and delays the turn back for the second pass, the problem becomes more complicated, as the results depend upon the path of the aircraft, and the target may reach the edge of the clearing. In addition, if $x_2 < R_a$ and $y_2 > R_a$ a re-entrant region and double value of the variable of integration ydx occurs. Care must be exercised in evaluation for these cases. The following expressions apply. Case V, attack circle intersects target circle twice within visual circle and re-entrant angle exists:

$$\begin{aligned}\text{ASPE} = {} & [(R_v^2 - 2R_a^2)/R_{\text{TC}}^2]/2 + [2R_t(x_2 - x_3) - \\ & (R_v - x_3)\{R_{\text{TC}}^2 - (R_v - x_3)^2\}^{1/2} + \\ & (R_v - x_4)\{R_{\text{TC}}^2 - (R_v - x_4)^2\}^{1/2} + \\ & x_3\{R_a^2 - x_3^2\}^2 + (R_v - x_2)\{R_{\text{TC}}^2 - (R_v - x_2)^2\}^{1/2} + \\ & x_2\{R_a^2 - x_2^2\}^{1/2} - (R_v - x_1)\{R_{\text{TC}}^2 - (R_v - x_1)^2\}^{1/2} - \\ & x_1\{R_v^2 - x_1^2\}^{1/2} - R_{\text{TC}}^2\{\sin^{-1}(R_v - x_1)/R_{\text{TC}} + \\ & \sin^{-1}(R_v - x_3)/R_{\text{TC}} - \sin^{-1}(R_v - x_2)/R_{\text{TC}} - \\ & \sin(R_v - x_4)/R_{\text{TC}}\} + R_a^2\{\sin^{-1}x_2/R_a - \sin^{-1}x_3/R_a\} - \\ & R_v^2 \sin^{-1}x_1/R_v]/\pi R_{\text{TC}}^2 \qquad (8e)\end{aligned}$$

Case VI, attack circle intersects target circle once within visual circle and re-entrant angle exists:

$$\begin{aligned}\text{ASPE} = {} & (R_v/R_{\text{TC}})^2/2 + [2R_t(2R_a - x_6 - x_2) + \\ & x_6\{R_a^2 - x_6^2\}^{1/2} - x_2\{R_a^2 - x_2^2\}^{1/2} - \\ & (R_v - x_2)\{R_{\text{TC}}^2 - (R_v - x_2)^2\}^{1/2} + 2(R_v - R_a) \times \\ & \{R_{\text{TC}}^2 - (R_v - R_a)^2\}^{1/2} - (R_v - x_1)\{R_{\text{TC}}^2 - \\ & (R_v - x_1)^2\}^{1/2} - x_1\{R_v^2 - x_1^2\}^{/12} - R_{\text{TC}}^2\{\sin^{-1} \\ & (R_v - x_2)/R_{\text{TC}} + \sin^{-}(R_v^1 - x_1)/R_{\text{TC}} - 2\sin^{-1} \\ & (R_v - R_a)/R_{\text{TC}}\} - R_{a2}\{\sin^{-1}x_2/R_a - \sin^{-1}x_6/R_a\} - \\ & R_v^2 \sin^{-1}x_1/R_v]/\pi R_{\text{TC}}^2 \qquad (8f)\end{aligned}$$

$$R_{\text{TC}} = V_{t_g}\{(2R_c - R_r) + Vt^* + R_t[\pi + 2\tan^{-1}R_t/R_c]\}/V$$

t^* is delay time.

13. Attack and Weapon Delivery

In COIN situations, the target will be attacked at low V and h by guns, rockets, grenades, parafrag bombs, bombs, and/or other stores on the first or subsequent pass using only the simplest aiming devices, such as fixed ring sights or fixed reticule sights. In COIN, there are constraints on weapon delivery which do not exist in limited war; weapons may not be employed until positive target identification, and

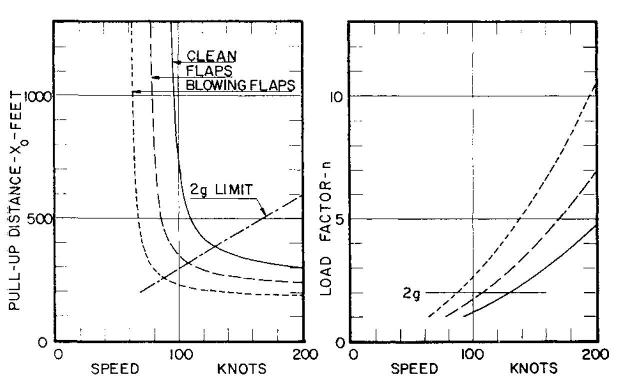

Fig. 12 Pull-up distance over a 50-ft obstacle as a function of flight speed for three lift configurations and a 2g limit, and load factor in pull-up as a function of flight speed.

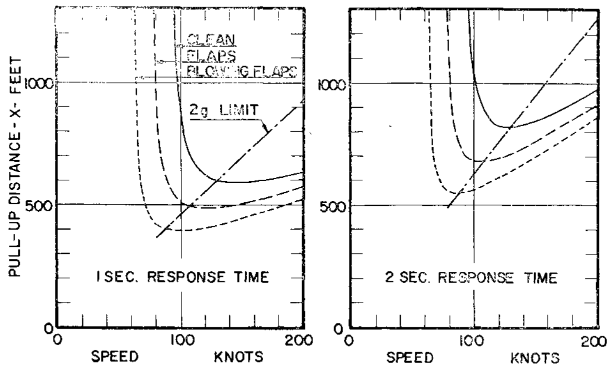

Fig. 13 Pull-up distance over a 50-ft obstacle as a function of flight speed for three lift configurations and 1- and 2-sec aircraft response time.

the short time and distance require a high volume of precise delivery to be effective and minimize nonessential damage to property. In order to assess these problems, the following model was used: the aircraft is approaching a potential target at near ground level at a const V, and at the distance R_v, the target is identified and attack begins. The target is assumed to be at the base of a 50-ft obstacle, so that the aircraft must pull-up to avoid striking the obstacle. Assuming const V and n in the pull-up, the distance in front of the obstacle that the pull-up must start can be calculated from $X_{50} = [2Rh - h^2]^{1/2} = [2hV^2/g(n - 1) - h^2]^{1/2}$, where h is the height of the obstacle. The aircraft must be able to develop the required n at each V, and if lift limited, the distance becomes

$$X_{50} = [4hW/g\rho SC_{L_{\max}}\{1 - (V_{\text{stall}}/V)^2\} - h^2]^{1/2} \qquad (9)$$

which is seen to have an asymptotic limit as V increases, and to become infinite at V_{stall}. In the g limited condition, X_{50} approaches asymptotically proportional to V. It is seen that increasing $C_{L_{\max}}$ will decrease, and increasing W/S will increase X_{50}. Thus, low wing loadings and high lift devices are mandatory for good performance in this maneuver. Figure 12a shows X_{50} vs V for three lift configurations, and Fig. 12b shows n vs V for each lift configuration. Sufficient thp and control must exist to permit flight at all conditions. X_{50} is shown for both lift limited and $2g$ pull-up. thp limit pull-up may be computed from

$$X_{50} = [2hV^2/g[(\text{thp}_{xs}/\text{thp}_{\text{in}})^{1/2} - 1] - h^2]^{1/2} \qquad (10)$$

but unless severely power limited is not of importance.

The equations for X_{50} assumes that the airplane rotates instantaneously to the C_L used in the pull-up, although, in fact, a finite time is required for rotation and circulation development. Let the total response time from initiation of controls to actual start of pull-up be t^*, then $X^* = X_{50} + Vt^*$ is the actual pull-up or break distance. In Fig. 13 are shown the effect of $t^* = 1$ and 2 sec on X for three lift configurations and $n = 2$.

The attack time is $t_a = (R_v - X^*)/V$, and is important for two reasons: it determines the time the aircraft is exposed to hostile fire without any evasive maneuvers, and it determines the number of rounds expended on the target for guns, and hence the payoff. It is desired to fire the largest number of rounds at the target during attack to increase the probability of its neutralization or destruction. The number of rounds fired at the target is the cyclic rate of fire times the number of guns times the firing time, or

$$NR = (CRF)(NG)t = (CRF)(NG)(R_v - X^*)/V \qquad (11)$$

It is desired to maximize NR, that is, to find V to maximize NR. In Fig. 14 is shown NR vs V_k for X_{50} for each lift configuration and a $2g$ pull-up limit. The distance between the curves and two horizontal lines marked 1 and 2 sec corre-

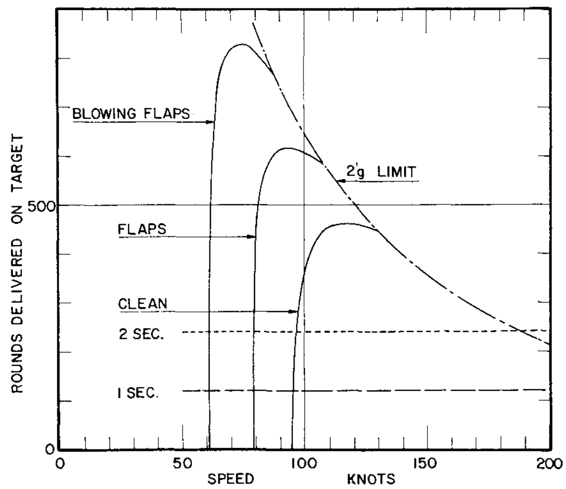

Fig. 14 Number of rounds delivered on target as a function of speed for three lift configurations and $2g$ limit with 0-, 1-, and 2-sec aircraft response time.

sponds to NR with $t^* = 1$ or 2 sec. It is seen NR is maximized at less than $2g$, and occurs at V less than for minimum X_{50}. Physically, more firing time is obtained by flying slower, even though it is necessary to terminate fire at a greater X. With guns properly harmonized and a 4-mil dispersion, all rounds would be contained in a 10-ft circle. A maximum average density 11.4 rounds/sq ft can be achieved for 6 guns with $CRF = 1200$.

In R/S missions, unmarked targets must be attacked at low h and V, and small θ, because of the sensor limit. If the target is marked, higher V, h, and θ may be used, but in some situations ground missiles and antiaircraft fire limit the h from which the dive may be initiated. Assuming simple sights, a study of dive-bombing errors for the effect of h_c, h_r, h_i, and pull-up n was made. It was assumed a $1g$ normal acceleration pushover at const V was used, and time t in a steady dive for aiming, release, t^* for aircraft response, and a $2g$ pull-up, with $h_c = 100$ ft, $h_c = h_i/11$, or $h_c = 2h_i/11$. Figure 15 illustrates dive-bombing paths and defines h_i, h_r, h_{res}, and h_c. Two paths at 30° are shown, one using a $2g$ pull-out and one using an $8\frac{2}{3}g$ pull-out. Both have the same error, but greatly different initial positions. Two hemispheres with radius R_{resl} and R_v are also shown. Both paths initiate outside R_v, but the $2g$ path has a lower h_r and h_c, and is more nearly acceptable for COIN. A 90° dive angle path is shown for comparison. Although having zero error, it must be initiated high, and h_r is above R_v, an unacceptable situation. In COIN, aircraft must stay within R_v, so that dive bombing is not suited to COIN unless man-sized targets are marked clearly.

The error DBE is the amount the bomb trails the line of sight as it acquires velocity in falling. Because of the low V used, vertical acceleration in a vacuum was used for simplicity. The error may be calculated from

$$DBE = \cos\theta[h_r/\sin\theta - (V^2 \sin\theta/g) \times \{[1 + 2gh_r/V^2 \sin^2\theta]^{1/2} - 1\}]$$

$$h_i = (1 + f)[\{[n_i/(n_i - 1) + n_f/(n_f - 1)] \times (1 - \cos\theta) + (n_f - n_i)/2\}2W/g\rho SC_{L_{\max}} + (t + t^*) \sin\theta[2n_f W/\rho SC_{L_{\max}}]^{1/2}] \quad (12)$$

$$n_f \neq n_i, t = 0 \qquad \text{and} \qquad n_f = n_i \quad t = 2.5 \text{ sec} \quad (13)$$

$$h_r = [\{fn_i/(n_i - 1) + (1 + f)n_f/(n_f - 1)\} \times (1 - \cos\theta) + f(n_f - n_i)/2]2W/g\rho SC_{L_{\max}} + (1 + f)t^* \sin\theta[2n_f W/\rho SC_{L_{\max}}]^{1/2} \quad (14)$$

where n_i is the load factor in push-over, n_f is load factor in pull-up, and $h_c = fh_i$. The results are shown in Fig. 16 for $t^* = 0$. If the first pass attack is held to $h_i \leq 1000$ ft and $h_c = 100$ ft is used, it is seen $DBE \cong 120$ ft at 30° dive angle. Much steeper angles require much higher h_i, and little improvement in accuracy is obtained until 60° is reached where $h_i = 2500$ ft $> R_v$ is required. Increasing h_c increases DBE, h_r, and h_i. When $t^* > 0$, conditions change, and Fig. 17 shows the results for $t^* = 1$ sec. Larger errors occur at all dive angles, DBE is more sensitive to θ, and h_r and h_i increase. $H_c > 100$ ft are probably required to avoid bomb fragments of some bombs, but grenades and parafrag bombs permit very low altitudes. This raises the question of how closely the attack can be pressed and its effect.

The effect of using higher g's in pull-out at an angle of 30° and $125K$ initial speed is shown in Fig. 18 for $t^* = 0$ and Fig. 19 at $t = 1$ sec. The higher g's reduce DBE for fixed h_c, but for $h_c = fh_i$, there is an initial reduction in DBE, and then an increase as h_c and h_i are increased to obtain higher g's. It is seen that for $h_i = 1000$ ft, a maximum of 2.4 g's should be used for the 30° dive. There is little or no advantage to be gained by using high g's and aggressively pressing home the attack.

A study of weapons effect was conducted to determine those best suited for COIN and the quantity needed to produce given levels of effectiveness. From consideration of COIN target deployments and munitions effects, the total useful load (fuel, sensors, and munitions) which should suffice for most missions was determined. These results are classified, but the aircraft should have the capability of carrying a large number and variety of weapons ranging from small machine guns to large munitions.

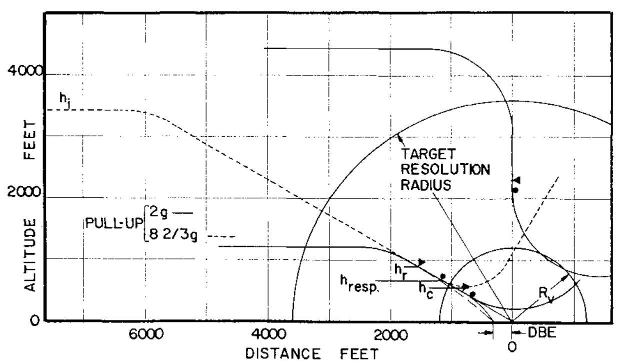

Fig. 15 Dive bombing flightpaths at 30° and 90° with $1g$ push-over and $2g$ and $8\frac{2}{3}g$ pull-up.

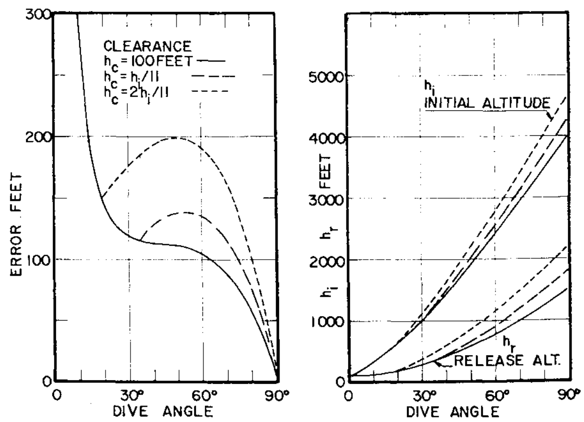

Fig. 16 Dive-bombing error, initial altitude, and release altitude as a function of dive angle for $125K$ speed.

14. Load Factor

If the aircraft were to be used solely as a pure COIN aircraft, moderate load factors could be used since the analysis has shown most maneuvers occur in the lift limited regime and $n \geq 2.5$ would seldom be employed. Because of the STOL characteristics, a high V and h capability is also obtained. In dash at low h, gust loading can reach 7 to 8 g's, and in dive bombing and high power maneuver similar g's are obtained. Since the aircraft also may be used as an attack aircraft, the n for structural calculations was set at a maneuver $n = 8.67$, that required for attack aircraft. Since the aircraft may operate as a fighter-bomber at short ranges in ground support missions, this n capability must be based upon the combat designs gross weight at takeoff.

15. Evasive Action and Withdrawal

During search, loiter, and attack modes, it has been shown that for high effectiveness the aircraft must fly low and slowly. It must have excellent maneuverability in turns and pull-ups, but these are essentially lift or g limited. If strong hostile fire is encountered, one of the most effective defenses for survivability is rapid acceleration and/or climb to withdraw from the area. The capability to accelerate to high V in short time and distance depends on large thp_{xs} and very rapid engine acceleration and propeller pitch change. These features are seldom found in turbine power plants, are good in reciprocating engines, and excellent in rotating combustion engines. It would be desired to go from loiter power, essentially $(\text{thp}_{\text{req}})_{\min}$, to full power in less than $\frac{1}{2}$ sec, but 1 sec would be acceptable. To determine the aircraft acceleration time and distance, one has from energy considerations $d(h + V^2/2g)/dt = dh/dt + (V/g)dV/dt = dh/dt + (V^2/g)dV/ds = 550(\eta\text{bhp} - DV)/W = 550(\text{thp}_{\text{av}} - \text{thp}_{\text{req}})/W = 550\ \text{thp}_{xs}/W$. In integral form, using the mean value theorem, one obtains

$$t = \int dt = \left(\frac{1}{550\,g}\right)\int_1^2 \left(\frac{W}{\text{thp}_{xs}}\right) VdV = \frac{\overline{(W/\text{thp}_{xs})}(V_2^2 - V_1^2)}{1100g} \qquad (15)$$

and

$$s = \overline{(W/\text{thp}_{xs})}(V_2^3 - V_1^3)/1650g \qquad (16)$$

Also $R/C = 33{,}000/(W/\text{thp}_{xs})$.

From studies of the ability of personnel to swing guns and bring ground fire to bear on the aircraft, the required acceleration and distance can be determined. An acceptable value of $\overline{(W/\text{thp}_{xs})} = 6$ gives time to accelerate from $100K$ to $200K$ in 15 sec and within a distance of 3800 ft, and a rate of climb potential of 5500 ft/min. At a desired value of $\overline{(W/\text{thp}_{xs})} = 4$, one obtains 10 sec, 2500 ft, and 8250 ft/min. These are severe requirements, but can be achieved using multiple lightweight powerplants geared together. The rotary combustion engine is ideally suited for this, since at loiter, unneeded engines are shut down, but the rapid response of the engine permits full power to be obtained in less than 1 sec.

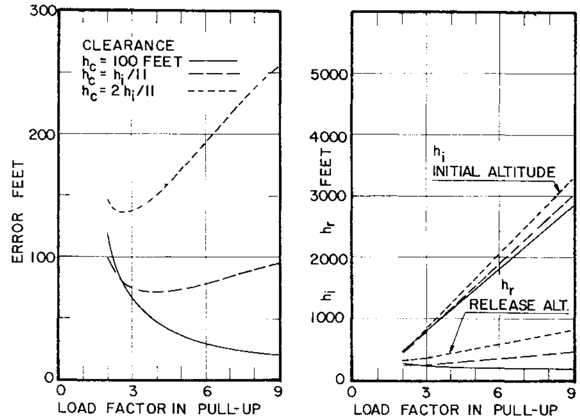

Fig. 18 Dive-bombing error, initial altitude, and release altitude as a function of g's in pull-out for a $125K$ initial speed.

16. Return to Base

In a large percentage of the missions, the munitions would not be expended, but returned to base. Low-altitude return at best cruise is desired to detect targets of opportunity, and deter insurgent activity by the aircraft's presence. $V_k < 150K$ would be desired to improve the sensor capability.

17. Landing

Landing may be made with full sensor and weapon load in a large percentage of the missions under minimal conditions of visibility. Reverse pitch propellers and cross wind landing gear operable on wet sod are desired, especially for civic actions in remote areas. Landing gear designed for a rate of sink = 20 fps and rough field operation is mandatory. Although the study was done quantitatively wherever practi-

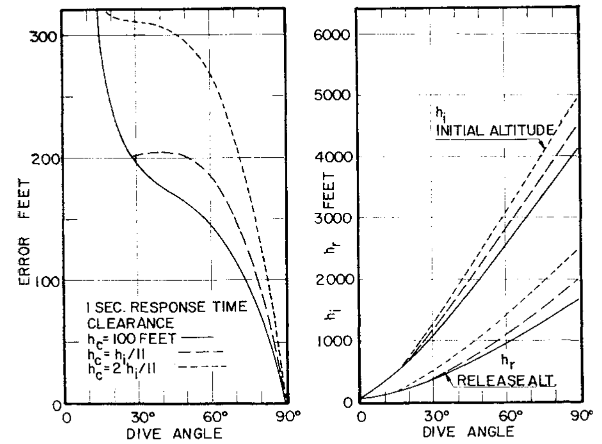

Fig. 17 Dive-bombing error, initial altitude, and release altitude as a function of dive angle for $125K$ speed and 1-sec aircraft response time.

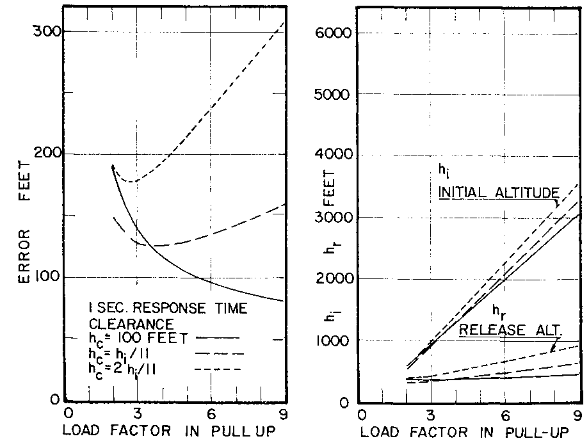

Fig. 19 Dive-bombing error, initial altitude, release altitude as a function of g's in pull-out for a $125K$ initial speed and 1-sec aircraft response time.

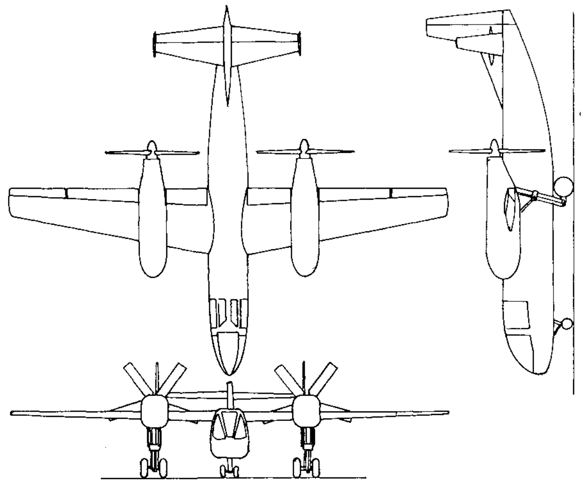

Fig. 20 Typical COIN aircraft configuration to satisfy requirements.

cal, only a qualitative discussion of results has been permitted to be released for this publication.

Capabilities of Current Aircraft

While developing the requirements,[1] an analysis was also made of the capabilities of known operational, prototype, and conceptual aircraft.[6] Prior to knowing the requirements, all aircraft were considered as potential COIN aircraft which satisfied the following conditions: gross weight less than 100,000 lb; payload greater than 1000 lb; and mission radius greater than 150 naut miles. Approximately 160 aircraft, both foreign and U.S., were found which satisfied these conditions. The essential performance information for these aircraft was entered on punch cards for ease of sorting and computation. As requirements were developed, aircraft that could not satisfy a mission radius of greater than 200 naut miles, takeoff roll of less than 4000 ft, bomb delivery capability, and availability of necessary performance data were eliminated from further consideration, but with the digital computer program developed could always be reconsidered if desired. Only 66 aircraft remained for further consideration, including 14 conceptual aircraft evolving from the aircraft design model to be discussed later. These included reciprocating engines, turboprops, and rotary combustion engines.[7–9]

The effectiveness of these aircraft was then evaluated by developing a digital computer model.[1] The effectiveness criteria were based on the takeoff distance, radius of action, loiter-sensor-munitions useful load, and low-speed capabilities. The model calculates the maximum gross weight that a given aircraft can take off from a given length of runway with a given surface condition. Knowing the allowable gross weight and the fly-away weight, fuel used for taxiing, takeoff, climb to altitude, dash or best cruise to target, best cruise back to the base, reserve, landing, and taxiing were calculated. The difference between this sum and the allowable gross weight for takeoff for the runway condition is the aircraft's useful load capability. The next step was to divide this useful load in the optimum manner among the sensors, munitions, and loiter fuel. To find this optimum distribution, curves were drawn of effectiveness vs loiter time, effectiveness vs sensor weight, and effectiveness vs munitions weight for a given mission. The effectiveness values are numbers between zero and one which are related to the conditional probabilities that each of the functions represented by loiter time, sensors, and munitions will be successful. The loiter time effectiveness, for example, is related to the probability (given successful arrival at the target area within the allowable reaction time) that the loiter time capability is sufficient to allow the field of view of the sensors to encompass the target. The sensor effectiveness is the probability of target detection if that target comes within the sensor's field of view. The munitions effectiveness is related to the probability of target neutralization given detection. Due to these relationships with conditional probabilities, the product of the three effectiveness values for loiter, sensors, and munitions was taken as a rating of mission effectiveness. The division of weight among loiter fuel, sensors, and munitions was varied over all possible combinations (whose sum equalled the useful load capability) to determine the particular distribution which has the largest value of mission effectiveness rating. This procedure was repeated for 25 different missions, 5 different mission radii, 3 different runway lengths and 5 different runway conditions. A weighted average of the results was then calculated and used as the effectiveness rating assigned to the particular aircraft. Those aircraft which rated well on the basis of these criteria were then examined more closely in terms of other important requirements of a less quantitative nature such as visibility, simplicity, and versatility for other types of missions. In this manner, the best existing aircraft for COIN were selected.

Compatibility of Requirements

Early in the evaluation, it became obvious that many existing aircraft were entirely unsuited for COIN operations, but a few were excellent. Several rated very high, but unfortunately, these aircraft were old, few in number, and out of production. To put them in production would cost as much as to design a new aircraft. Up to this point in the analysis, there had been no question of the compatibility of the requirements, the possibility of an aircraft being able to satisfy all of the requirements, or if this were impossible, the performance tradeoffs which would produce an acceptable vehicle, and whether or not a totally new aircraft could be designed which could satisfy all of the requirements. Techniques had been developed at the Air Force Institute of Technology which could assist in the solution of these problems, and they were ideally suited for use with digital computers.

Optimization of a Typical COIN Aircraft Configuration

An aircraft configuration embodying characteristics determined by the analysis was developed[1,9–12,16] and is shown in Fig. 20. This configuration can be modified easily for different propulsion system.

To find the optimum aircraft the method of Ref. 1 was used. In this procedure, aspect ratios from 6 to 15 were

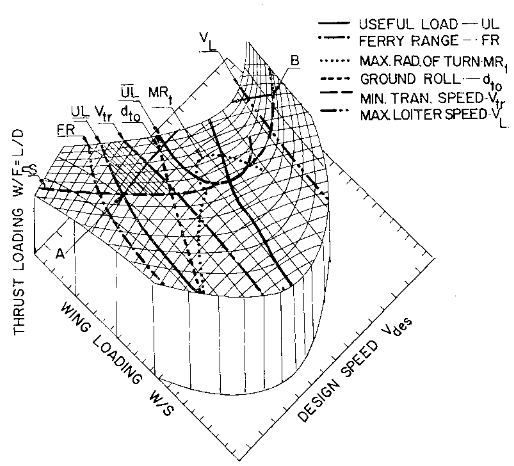

Fig. 21 Generalized performance surface used in optimization.

studied using a "rubberized" model of the configuration. Power levels of 400, 750, 900, 1125, 1680, 2250, 3000, 3375, and 3750 bhp per nacelle, and design altitudes, h_{des}, of 15,000, 20,000, and 25,000 ft were used. Since performance can be expressed as functions of W/S, W/bhp, V, L/D, S, A, and W_i/W_f, choosing any three as primary variables, specifically W/S, V, and L/D, a three-dimensional surface representing the performance capability of an infinity of aircraft is obtained.[1] Performance tradeoff can be visualized readily. A sample is shown in Fig. 21. This surface has been named the generalized performance surface. Lines of const V, S, and W/S are plotted in the surface, and the intersection of S and W/S line in the surface completely describes the aerodynamic and internal weight breakdown according to the scheme used.[13] Using standard performance techniques such as in Refs. 14, 15, and a digital computer program,[1] the complete performance of aircraft at each intersection of V and W/S was calculated. Contours of constant performance were then plotted on the surface, such as R/C, R_t, d_{to}, ferry range (FR), useful load capability for prescribed missions (UL), effectiveness (E), cost (C), and cost effectiveness (C/E). The specific values developed for the requirements were plotted to locate that area on the surface, if any, where all performance requirements are satisfied. For example, the line marked FR is one of a family, and is a boundary between all aircraft that do or do not have sufficient FR. Points lying above and to the right have more FR capability than needed. The line marked $\underline{UL}$ (bars below) is the boundary for the minimum UL required to achieve a prescribed capability of accomplishing, say 90%, of all 1875 missions and the line marked $\overline{UL}$ corresponds to 99% capability. Any aircraft lying between these lines is acceptable. The line marked d_{t0} is the minimum acceptable takeoff distance, and any point lying to the left is acceptable. The line marked MR_t is the maximum acceptable radius of turn for effectiveness. Any point to the left is acceptable. The S = const line indicates the limiting wing area for UL (bars below) aircraft which can be overloaded to accomplish $\overline{UL}$ needed for long-range missions. The line marked V_L is the maximum allowable loiter speed for effectiveness, and any point to right is acceptable. To determine this, a point at S = const and W/S = const is projected from the left intersection such as the point A to the right intersection at the point B. If B lies to the right of V_L, the aircraft is acceptable. The line marked V_{tr} is the minimum acceptable transit speed used in transit to the target. Any point lying to the left is acceptable. In the sample shown, it is seen UL (bars below) is more critical than FR, so that to improve UL (bars below), FR can be degraded if desired. Similarly, d_{t0} is more critical than MR_t, and MR_t can be degraded, if desired. Furthermore, V_{tr} can be increased, if desired, by reducing the weight. The area defined by UL (bars below), V_{tr}, d_{t0}, and S = const defines all acceptable aircraft. The final choice is determined by plotting contours of growth factor, E, C, and C/E, and usually occurs near the point A. In this manner, the optimum aircraft for a given bhp, A, and h_{des} is found. By cross plotting E, C, C/E vs A, bhp, and h_d, the final choice is made, and all parameters for the optimum aircraft are known.

Conclusions

A general study of counterinsurgency has been performed, and has shown methods by which realistic aircraft system requirements can be formulated, and using standard configuration development techniques how compatible system requirements and how a superior multipurpose aircraft can be optimized.

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