ASUR

ECOLE POLYTECHNIQUE FEMININE

INTRODUCTION

The Ecole Polytechnique Feminine (E.P.F.) is a French engineering school for women. The students who presented the project at the Summer Conference are in the fourth year of a five year program. For the second time, the E.P.F. worked on a aeronautical project with the Ohio State University. This year, the theme of our study was to design a hypersonic carrier aimed to launch an orbiter at Mach 6, a range of 375 miles and an altitude of 95,000 ft.

We called our plane ASUR. In French ASUR means the blue sky, the same sky that links our countries across the ocean. Moreover, ASUR is an anagram of USRA.

This work benefits from work on reusable hypersonic aircraft in Europe, and especially on two of them: STAR-H and Sanger. STAR-H is a French project. This hypersonic aircraft would replace Ariane 5 in launching a shuttle smaller than Hermes. Sanger is a German project. Its objective is to launch a manned shuttle called HORUS, but Ariane 5 would be kept for heavy cargo launches. These two projects are in competition in Europe to be a launcher of the European Space Agency.

GEOMETRY

The carrier's geometry (Fig. 1) has been determined from the fuel volume necessary to accomplish the worst case mission scenario: that separation is impossible and the carrier comes back with the orbiter and lands with almost no fuel.

The parameters known at the beginning of the study were the weight of the orbiter: $W_{orbiter}$ = 136 tons (2,990,823 lb), and the specific impulse of our engine: I_{sp} = 2000 s.

Some other data we needed were given by other work on hypersonic aircraft: ΔV = 400 m/s; carrier's dry mass $Wd_{carrier}$ = 166 tons (366,030 lb); takeoff velocity TOV = 100 m/s; the lift-off coefficient $C_{lift\text{-}off}$ = 0.37; the aspect ratio λ = 1; and body width is equal to 1/3 of the wing span.

These data allowed us to calculate the fuel volume, the plane's geometry, and the tank specifications.

Fuel Volume

The carrier's takeoff gross weight (TOGW) and fuel volume (V) were found to be TOGW = 370 tons (815,850 lb), and V = 971.3 m^3 (256,645 gallons), respectively.

Geometry

The wing area is simply deduced from the equation S = 1600 m^2 (17,222 sq ft). The span of the delta wing is also easily obtained : b = 40 m (131 ft).

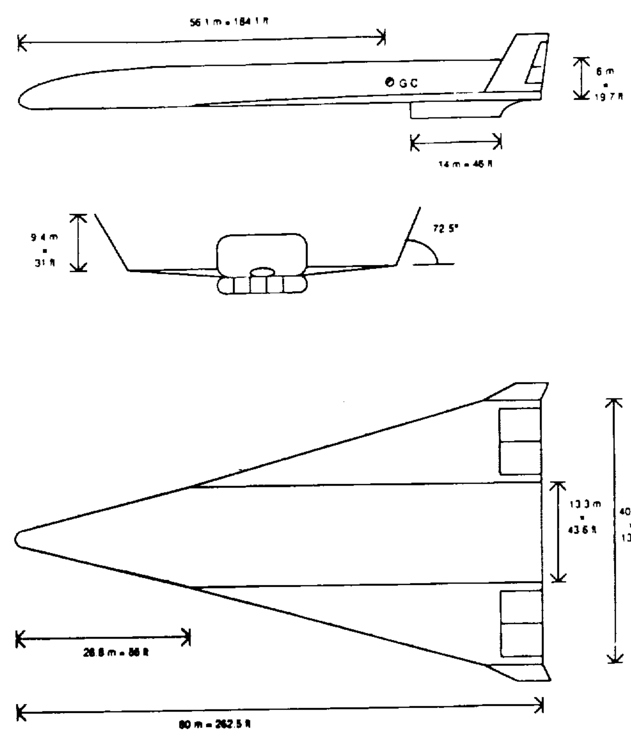


Fig. 1. ASUR 3-view.

We know that the body width is equal to 1/3 of the wing span and that the forward section has to remain constant, so we deduce the dimensions of the backward body as seen in Fig. 2.

Current work on hypersonic design advises us to take a wing sweep of 74°, from the beginning of the backward body. We also obtain the length of the winglets (8 m). Moreover the winglets are designed to provide better aerodynamic efficiency; that's why the extremities of the winglets of the carrier and the orbiter are in the same plane.

For the given backward body dimensions, we have two possibilities to store the required volume of hydrogen, using two or three tanks of the same length. We choose the 2 tanks configuration because it allows us to put an extra small tank between the two large ones.

Weight

To estimate the weight of different parts of the aircraft (Table 1), we use a statistical approach using several of Concorde's derivation methods and also methods applied to high speed military aircraft.

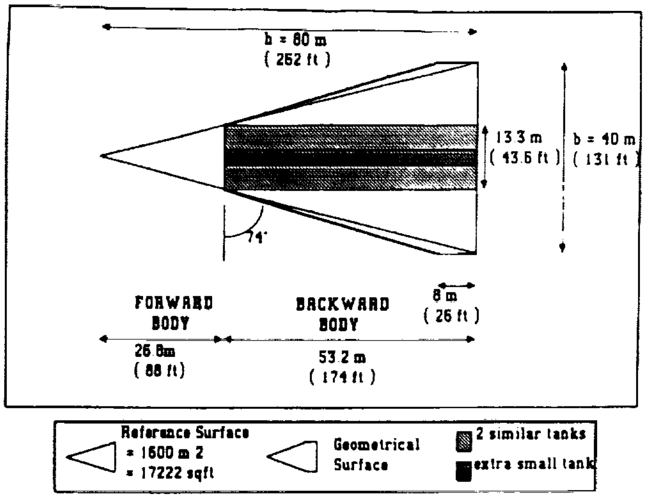


Fig. 2. Geometry.

TABLE 1. Component Weights and c.g.

Component	Weight tons	Weight lbs	Center of Gravity Position x_i m	Center of Gravity Position x_i ft
Wings	42	92593	59	193.6
Forward body	5.35	11795	17.6	57.74
Backward body	36.65	80798	53.2	174.5
Winglets	6	13228	78	255.9
Nosegear	1.3	2866	17.6	57.74
Principal nosegear	11.7	25794	55.9	183.4
Engines	16	35273	69	226.4
Inlet	10	22046	61	200.1
Tanks	14	30864	53.2	174.5
Fuel system	4	8818	53.2	174.5
Flight control system	3	6614	55.9	183.4
Auxiliary control system	0.1	220.5	55.9	183.4
Instruments	0.1	220.5	17.6	57.74
Hydraulic system	7	15432	55.9	183.4
Power supply	3.5	7716	55.9	183.4
Navigation & communication	1	2205	17.6	57.74
Installations	2	4410	55.9	183.4
Oxygen	0.04	88.2	17.6	57.74
Fire extinction	0.2	441	69	226.4
Air conditioning & APU	1	2205	55.9	183.4
Defrosting	0.2	441	55.9	183.4
Ventilation	0.3	661.5	17.6	57.74
Crew	0.4	882	17.6	57.74
Fuel unfit for consumption	4	8818	53.2	174.5
Oil	0.1	220.5	55.9	183.4
TOTAL	170	374779		

STABILITY

To analyze the stability, we calculate the relative position between the center of gravity and the aerodynamic center. We can observe that the aerodynamic center (F) is positioned just before the center of gravity (G) in reference to the aircraft's nose (O); OG = 56.13 m (184.7 ft); OF = 55.9 m (183.4 ft).

Thus our plane can be considered slightly unstable. But at supersonic and hypersonic speeds, the aerodynamic center moves backward by approximatively 12 m and makes it stable. Moreover, a computer simulation shows that the little unstability of our aircraft can be easily corrected with automatic flight controls.

MATERIALS

Because ASUR flies at high speed (Mach > 4), its structure will experience high temperature. The materials that will be used for the structure, need to have light weight, good mechanical properties, resistance to corrosion and ablation, reusability, and good protection of the rest of the aircraft from heat.

There are several possibilities. They include titanium materials (but temperatures between 900°F and 1000°F damage the structure); carbon-carbon materials which keep their specifications of resistance at high temperatures; and titanium/plastic alloys joined to a new aluminium/titanium and carbon composite which resist high temperatures and decrease the weight of the plane. We choose this last solution but they are not yet developed.

Whatever material is chosen it will undoubtedly face the same kind of problems. Thermal gradients cause heat fatigue which is very harmful for a plane that has to be reusable. The discontinuity of temperatures lead to internal stresses and deformations that can induce cracks in the structure (the tanks). A dangerous brittleness of the steel landing-gear appears at 200°C, so they must be protected. The equipment necessary for heat protection (fuel, landing-gears) and the recooling of the leading edge of the wings will make the aircraft heavier.

PROPULSION

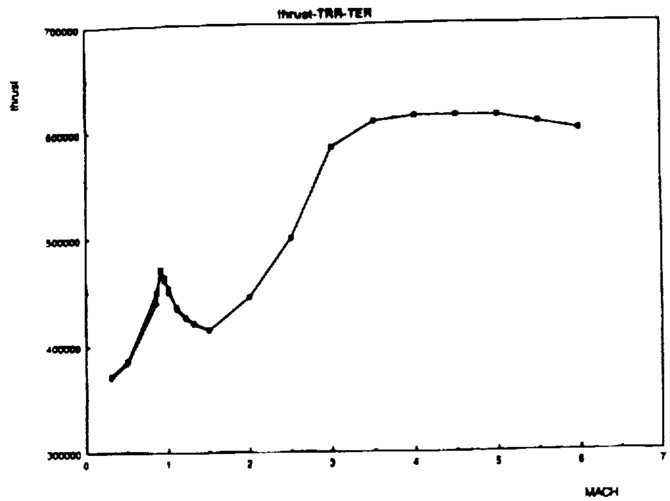
The optimization of future space launchers depends mainly on the choice of the combined cycle propulsion concept. We use two solutions: the turbo-rocket-ramjet and the turbo-expander-rocket (Fig. 3). The choice between these two solutions is difficult because both engines have similar performance. But all the mission calculations have been made with the turbo-expander-rocket.

Turbo-Rocket-Ramjet (TRR)

The TRR flies in a rocket mode to Mach 3 and them in a ramjet mode. The airbreathing operation of a turbo-rocket-ramjet is limited to a flight Mach number of about 6 because of high temperatures. The specific impulse is not very high compared to some other combined cycle propulsion concepts but it has the advantages of a lower weight and less technological complexity.

Turbo-Expander-Rocket (TER)

Hydrogen is heated before burning in the combustion chamber, which allows the gas to be released through the turbine. Thus we have an expansion effect, not a combustion effect, which is why the engines consume less and the specific impulse increases. But drawbacks are the weight and the technological complexity of the cooling system.



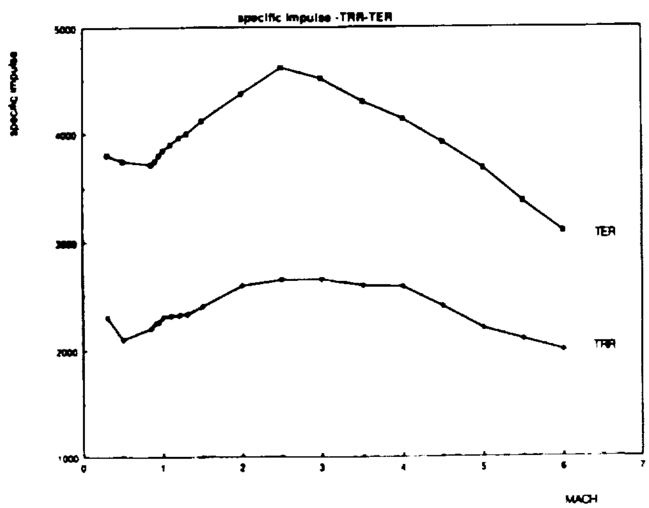


Fig. 3. Thrust and Specific Impulse Calculations.

We have to launch the orbiter at Mach 6 at 30 kilometers, so we need 5 airbreathing engines. They are necessary to overcome the drag rise at Mach 1.3.

Fuel

For a hypersonic aircraft, fuel determines the structure of the plane because of storage and tank dimensions. We use cryogenic fuel. We have three possibilities: LH_2 + LOX; LH_2; or Methane. Methane has a very high density and can be used easily but it has a very short functioning time and is less energetic than the others.

LH_2 and LH_2 + LOX are more energetic and have a longer functioning time. Moreover, they can be used to cool the structure, but the supply system is complex and storage is difficult.

LH_2 + LOX and LH_2 are the best solutions for future hypersonic aircraft. We choose LH_2 because LH_2 + LOX increases the takeoff weight. Instead of LOX, ASUR uses oxygen from the air because it flies below 35 km and we consider that the atmosphere has enough oxygen density at those altitudes. The obiter uses LH_2. If it can't be launched, ASUR has to return with the orbiter and more fuel will be consumed than has been planned. Because the orbiter and ASUR use the same fuel, ASUR could use fuel from the orbiter to return. On the other hand, if the launch can be made, ASUR could top off the orbiter's tank just before the separation.

Inlet

We choose the Sanger solution of 5 separate inlets, one for each engine.

DRAG

We calculate first stage drag and composite drag and compare the two to show the influence of the second stage on the first stage (Fig. 4).

For the drag polar equation $C_d = C_{d_0} + k \cdot C_l^2$, C_{d_0} is the zero lift drag coefficient and k the induced drag coefficient. We calculate these two coefficients (Fig. 4). On the C_{d_0} curves, we can see that the orbiter has more influence in the supersonic and hypersonic domain than in the subsonic one because of the wave drag which depends on pressure distribution. The C_l/C_d ratio decreases until Mach 1.3 and then it increases regularly, but it doesn't reach very big values. This ratio has been calculated during the climb part of the mission. The thrust-drag curve of the composite shows us that we need 5 engines to overcome the drag rise at Mach 1.3.

MISSION

Some mission specifications are expected to allow the second stage flight. We have to launch the orbiter at Mach 6.0 with an altitude of between 95,000 and 100,000 ft at a range of 375 miles. From this information, we choose the mission profile (Fig. 5).

We decided to define a climb phase along a constant indicated airspeed as it was nearly the minimum fuel climb path to Mach 6.0, 95,000 ft. Then, the orbiter is separated from ASUR. And, ASUR alone, makes a turn and descends along the same constant indicated airspeed.

Climb Phase

The composite climbs along an constant indicated airspeed of 550 knots to the separation point. In order to verify our assumption, we ran a program that gives us the specifications and amount of fuel consumed at each flight point. Drag study results, engine curves, and the constant indicated airspeed curves were input to the program. With a takeoff weight of 370 tons (815,850 lb), the aircraft uses 40 tons (88,200 lb) during climb. With 64 tons (141,120 lb) of usable fuel remaining, we could achieve the mission, but the reserve fuel quantity wouldn't be acceptable. So, we decided to add a little tank between the

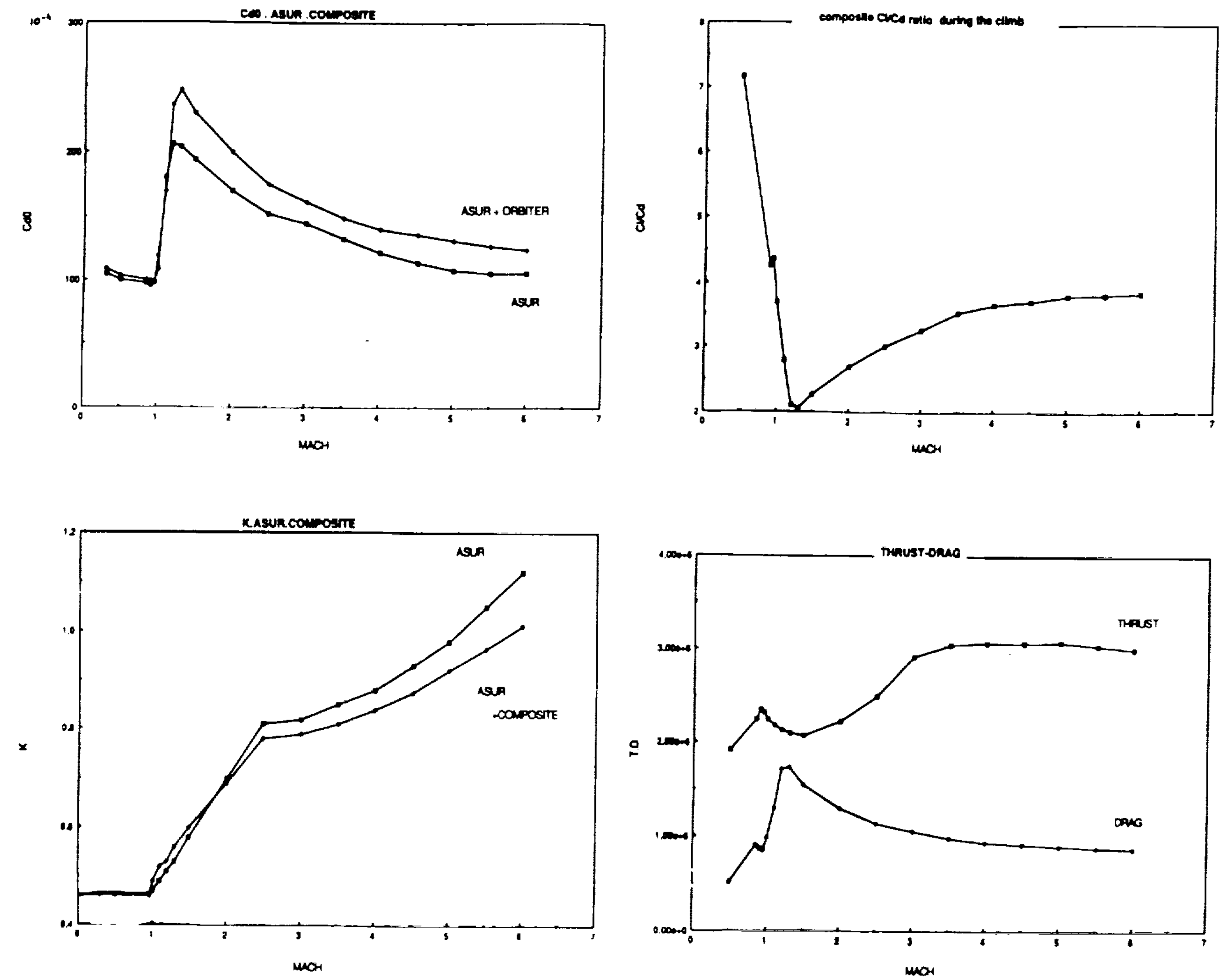


Fig. 4. Drag Calculations.

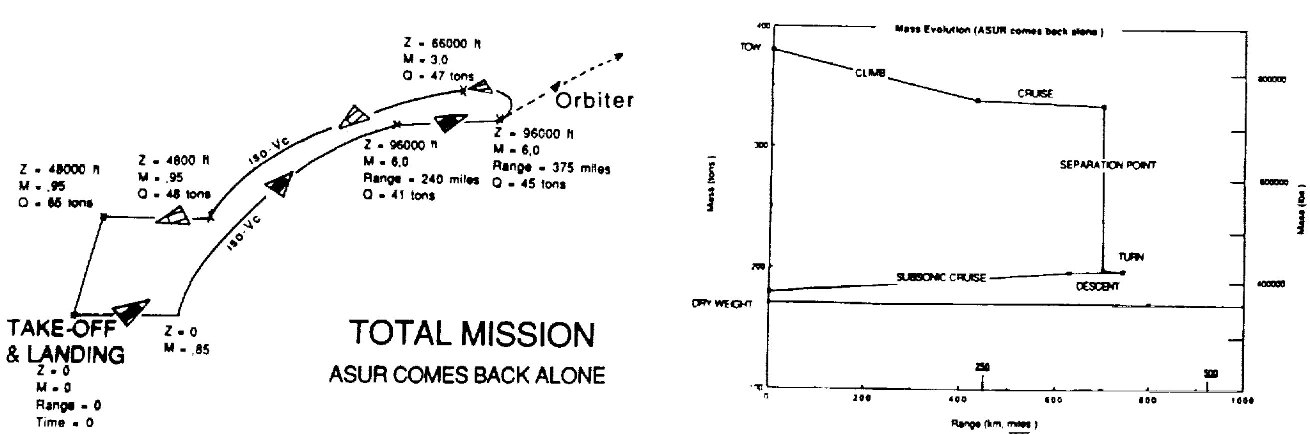


Fig. 5. Mission Profile.

two others containing 10 tons (22,050 lb). Even if we don't use the whole quantity of fuel, the excess would be used to fill up the orbiter's tank. We ran the program again with a takeoff weight of 380 tons (837,900 lb). We obtain a consumption of 41 tons (90,405 lb), with 33 tons (72,765 lb) of fuel left. The other results are equal to the specifications expected for the Mach number and the altitude, but the ranges are lower: 445 km (240 miles). To obtain the 375 miles expected, we decide to add a hypersonic cruise of 135 miles consuming 4 tons (8,820 lb). Notice that we keep the constant indicated airspeed until Mach 6.0 because the combustion chamber doesn't reach its limitation at this speed.

The Separation Point

At this point, the orbiter needs to be sustained because it is not launched with its engines operating. To achieve this, there must be a way of off-setting it from the carrier craft. We can think about jacks to put the orbiter in incidence. We can also imagine a separation similar to missiles. In this case, ASUR is going down when the orbiter goes straight on. Between these two solutions, the most realistic is the second one: jacks won't withstand very high temperatures.

Return Phase

We also examined the scenario when the orbiter isn't launched. It is not the worst case because in this configuration ASUR can use the orbiter's fuel. We decide that the takeoff point is also the landing point. This allows the composite to take off from any coastal airport to minimize noise over populated areas. ASUR has to turn and reduce engine thrust. Then it descends at the same constant indicated airspeed and cruises subsonically ($M = 0.95$) at an altitude optimized to minimize fuel consumption.

Conclusion

Finally, we find the mission is successful. All the specifications are met and the consumed fuel quantity is lower than the usable fuel. Even if the orbiter is not launched, we find that the mission is successful. The time to climb is 750 seconds and the total time is 2,800 seconds for a distance of 1,000 miles when ASUR comes back alone and 3,400 seconds for a distance of 1,050 miles for the composite.

The next step is to loop the calculation and redefine the geometry and the masses.

TAKEOFF STUDY

To determine the takeoff run, we developed a program using takeoff gross weight : TOGW = 380 tons (837,742.5 lb); wing area = 1600 m^2 (17,222.3 sq ft); maximum lift = 0.53; drag = $0.0815 + 0.46 \cdot C_l^2$; lift gradient = 0.027/°; and maximum thrust = 1,900,000 N.

We obtained the following results: ASUR need 35.4 seconds to take off and a runway of 2.4 km (7,887 ft) which is the length of runways in traditional airports.

CONCLUSION

The aircraft we designed meets the specifications given by the Ohio State University. In France, people from aeronautical firms like Aerospatiale and ONERA were interested in our project and offered us their technical support. However, this project can't be considered as a conclusion in itself but as a first iteration which, we hope, could sustain later studies.

ASUR belongs to a new category of reusable launchers. It opens new horizons for space conquest.