Apr 1st, 8:00 AM

Preparations in Europe for a Possible Participation in the Post Apollo Program with a Space Tug

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When in October 1969 the NASA Administrator Dr. Thomas Paine announced in an address to the European Committee of Minister Alternates the invitation of the United States of America to Europe to participate in the Post Apollo Space Program, there were not then many technical details known about this program. The interested European Nations, however, in considering this invitation soon realised that such a participation would only be meaningful if, by their standards, a large amount of money were made available in order to achieve a certain partnership with the United States. This fact, however, could mean the sacrifice of an individual European space program. For that reason at the end of 1969 the following criteria for the technical items to be furnished by Europe were established: they should be

- identifiable subjects
- essential systems in the project
- with small interfaces with the US developed items.

As a further field of participation many European countries expressed their interest to be involved in the technology of booster and orbiter reentry aerodynamics and thermal protection, because these areas are new for a spacecraft and seem to have promising future applications.

With these targets given, very soon, besides the possibility of the development of a Space Station Module or later a RAM, the tug or orbit-to-orbit shuttle was recognised as best meeting the scope of the given criteria. Only an orbit-to-orbit shuttle can give the Post Apollo Space Transportation System the required flexibility to fulfill the large variety of missions, ranging from near earth orbit to planetary and lunar missions; thus it is an essential part of the project. Being a third shuttle stage or an orbiter payload, the tug is an autonomous system with a rather small number of interfaces with the two first stages, compared to other systems which are part of the booster or orbiter. These facts led the European Authorities in April 1970 to the decision to spend 0.5 Mio dollar on a pre-phase-A study for a European Space Tug. In this study it should be determined whether such a system could meet the mission range which is of interest to the Europeans and what could be the design solutions with the given shuttle performance as it was officially projected by NASA at the time. The countries which agreed to share the cost of this study are the ELDO member states Belgium, France, Germany, Italy, Netherlands and the United Kingdom and the two ESRO members Spain and Switzerland. According to this participation possibly industries from all of these countries should be involved in the work. (Fig. 1, 2).

On behalf of the European Space Conference, the ELDO Organisation (European Launcher Development Organisation) in Paris was charged to conduct the desired investigations and furthermore all studies related to the transportation system of the Post Apollo Program. The ESRO Organisation was charged to deal with all problems of the space station and the modules.

As a definition of the task, ELDO decided to investigate an unmanned system which is specially designed for geo-synchronous missions with payloads between 2 and 6 t. Retrieval capability and performance for planetary and other missions were asked to be studied as second priority. With the one shuttle flight cost of 4.5 Mio dollar, a cost evaluation was required to compare it with conventional expendable launching vehicles, a comparison between space and earth-based systems was also wanted.
Among a number of leading teams, two were selected to conduct a 6 months pre-phase-A-tug system study starting on July 15th, 1970. One team consisted of the leader firm Hawker Siddeley Dynamics of the United Kingdom with ERNO and DORNIER of Germany, Fokker of Holland, MATRA and AIR LIQUIDE of France, FIAT and MONTEDEL of Italy, BELL TELEPHONE of Belgium and CONTRAVES of Switzerland, and the other of the leader firm MESSERSCHMITT-BOEIKNOW-BLOHM of Germany with SNIAS of France, BAC and ELLIOTT of the United Kingdom, SELENTA of Italy, CASA of Spain, ETCA of Belgium and CIR and FM of Switzerland.

These two system studies were accompanied by a complementary tug engine study by CRYOROCKET, an international company formed by SEP in France and MBB in Germany (Fig. 3).

The studies were conducted with monthly progress reports, a mid-term presentation and a final presentation in Paris at which representatives of NASA participated, in order to assure coordination with the US-Study activities in respect to technical interfaces to avoid duplication of work. Finally, the study results were presented by the European contractors and EIDO representatives to a larger US-audience in the NASA centers, MSFC in Huntsville, MSC in Houston and the headquarters in Washington D.C.

With the restriction on the use of LH2 and LOX as propellant combination, with an Isp equal to 450 sec and the shuttle performance of 22 t into 185 km altitude at 28.5° inclination and a payload volume of a 18 m long cylinder with a diameter of 4.5 m, the study made it clear that 6 t of payload could not be placed into geo-synchronous orbit launched by one shuttle flight with the tug returning to the orbiter orbit. The traffic model investigation, however, showed that about four times in 10 years a 6 t payload would have to be launched into geo-synchronous orbit by one shuttle flight with the tug returning to the orbiter orbit. The traffic model investigation, however, showed that about four times in 10 years a 6 t payload would have to be launched into geo-synchronous orbit, in which case an expendable tug was assumed to be permissible. In this case, the volume restriction in the orbiter payload bay would allow a payload density of about 50 kg/m³.

While EIDO accepted this philosophy for the upper payload limit, the main attention of the study had to be given to the real orbit-to-orbit shuttle, i.e. a reusable vehicle. In this case the upper payload limit could only be reached by two shuttle flights using a 2 stage tug composed of two identical 15 t (MBB) respective 10.5 t (HSD) propellant vehicles, or in the case of one shuttle flight, only the payload would be below the given lower limit. In the latter case an apogee motor or kickstage of the BURNER II stage kind would considerably increase the geo-synchronous payload. This additional stage would be expendable. Another possible combination is the use of a two stage tug with the first stage reusable and the second stage expendable. Hereby, of course, two shuttle flights would be necessary and one tug vehicle only would be regained. In all these cases it was assumed that no tankfarm was yet available so the reusable vehicles are earth-based and have to be launched by the shuttle with their propellants.

In the preliminary design solutions, one constructor selected a 15 t propellant baseline tug (Fig. 4) which could serve as an expendable vehicle, or in the modular mode as a reusable two, or even multi-stage, vehicle. The second contractor maintained the purely expendable option of 16.5 t propellant (Fig. 5) and a 10 t unit tug for the modular mode (Fig. 6). In both cases an outer diameter of 4.20 m was assumed with separated LH2 and LOX tanks.

The thrust optimisation showed an optimum value of 5 to 8 t thrust. For this value with a vacuum Isp of 450 sec the CRYOROCKET company investigated a high chamber pressure topping cycle engine solution. The chamber pressure is 100 ata, mixture ratio 6 and the area ratio 160.

In the economic part of the studies it was found that the unmanned, however man-rated, tug, - because it will have to be flown several times with the manned earth-to-orbit shuttle -, could be developed for 350 to 450 Mio dollar; the unit production cost would be between 9 and 14 Mio dollar, depending on the size and complexity of the chosen system. The operational costs are very difficult to estimate because they depend very largely on the traffic model assumed.

Thus, at the end of January 1971, the first European ideas about a space tug were available and in a hurried process of 6 months about 20 European firms had been forced to deal with the problems of the Post Apollo shuttle program. This fact can be considered as the best possible preparation for a possible participation in the program with NASA.

In the meantime a number of decisions had been made by NASA for the shuttle of which an important one was the orbiter payload increase due to the fact that, for the nominal version, airbreathing engines were abandoned. Furthermore, NASA decided to conduct no special technical tug study during the year 1971 besides the investigation of some economical questions and the
use of existing upper stages of conventional launching vehicles for space tug

tasks.

These facts led ELDO to the decision to continue the pre-phase-A-tug studies for four months in order to adjust the design concepts to the new shuttle performance. (Fig. 7). As this is the only special tug investigation at present, it was decided to extend the mission range to lunar and planetary missions also, i.e. including the possibility of manned missions. The study was to start with a reference tug which will still be designed for the unmanned geo-synchronous mission and to investigate the further development and application for the other missions starting with the reference vehicle. As this pre-phase-A-study is practically a continuation of the past activity, two study contracts were awarded to the two teams led by HSD and MBB. The total funding is 0.4 Mio dollar. Final results are expected at the end of July 1971.

Since summer 1970, NASA and the European Space Conference have appointed Co-chairmen for the joint planning, control and evaluation of the tug studies in the United States and Europe. By this means a close cooperation should be guaranteed from the beginning and all necessary information should be exchanged so that parallel work and duplication are avoided and interface problems are clearly solved. The contact has already established a good working relationship and will finally lead to a realistic technical cooperation program.

Besides the pure technical studies ELDO will start an economical investigation on the tug. In this study the special advantages of a reusable tug will be investigated for a traffic model of the time period between 1980 and 1995. Basic assumption is the economic launching costs for the booster and orbiter stages compared with the conventional launchers available at present.

In the area of special tug technology, ELDO so far conducted no studies. There is an 55 Mio dollar preparatory program for the EUROPA III launching vehicle under its way with an essential part of the cost being devoted to predevelopment work for the LH2/LOX upper stage of 20 t propellants. As this stage is similar in size and nature to the tug so far no special technology activities were considered to be necessary. For the second part of this year however, ELDO intend to start a special tug technology program. In this program, these problems will be studied which are not covered under the EUROPA III work, i.e. rendezvous radar and laser, docking mechanism and meteoroid protection.

If the ESC/NASA cooperation is followed up, ELDO's intention is to start a phase A tug study at about October/November 1971. For this study ELDO has begun together with NASA to discuss the task definition and to define the input documents with respect to interfaces, safety, operations and shuttle performance. Following this study it would be possible to enter into phase B during 1972 and to enter into phase C during 1973.

This timescale would fit very well into the present shuttle schedule which assumes a first shuttle flight for April 1978 and an IOC for mid-1979. It would give Europe time enough for a development start on the tug as a contribution to the Post Apollo program up to 1975 when DOD and NASA want to decide whether to select an existing upper stage as expendable tug as an interim solution or to go with their European partners right from the beginning.

The described preparation in Europe shows that the problem has been seriously considered and that the project picks up speed in accordance with the shuttle project in the United States.
A CONCEPT FOR STUDY

A SINGLE STAGE & PAYLOAD
ONE SHUTTLE FLIGHT
A CONCEPT FOR STUDY

TWO STAGES & PAYLOAD
ONE SHUTTLE FLIGHT
EUROPEAN - TUG
PRE - PHASE - A - STUDY

TIME SCALE

R.F.P
6.5.70

PROPOSALS
DUE
20.5.70

STUDY
START
15.7.70

MID.
TERM
PRES.
15.10.70

FINAL
PRES.
REP.
15.1.71 31.1.71

APR
1970

MID. TERM
15.10.70

FINAL
PRES.
REP.
31.1.71

6 MONTHS

HSP-Team
L' AIR LIQUIDE
BELL TELEPHONE
CONTRAVERS
DORNIER SYSTEM
ERNO
FIAT
FKKNER/VFW
MARTA
MONTEDR

MBB-Team
L' AIR LIQUIDE
BAC
CASA
CIR/EFE
ELLIOTT
ETCA
SELENA
SNIAS
VAN DER HEEM

Engine-Team CRYOROCKET
MBB
SEP
After the final presentation of the European Tug Studies results in Paris, Huntsville (MSFC), Houston (MSC) and Washington D.C. (NASA H.Q.) and discussions with NASA, it is proposed to continue the European Tug Studies which were started as a Pre-Phase "A" over six months.

The continuation should be an extension of the Pre-Phase "A" activity for the following reasons:

- the first part of the study was of extremely short duration;
- shuttle specifications have changed in the meantime;
- the technical objectives of the tug should be extended and, finally:
- new and more detailed economic considerations are necessary.

The second phase of the European Pre-Phase "A" Tug Study should cover the following points:

1. broadening of the horizon of the tug for missions other than the special geo-synchronous orbit;
2. development consideration of a tug which will lead to a final version of the multi-purpose orbit-to-orbit system. This probably includes investigation of an evolutionary or a substitute mode during the course of development; for this the operational economic and technical aspects must be taken into account.
3. redefinition of the tug concept, with the latest performance specifications and operations, safety and maintenance interfaces.
4. adjustment of the tug development plan to the new shuttle target dates (1st flight - April 1978, IOC - mid-1979); with the possibility of a propulsion module of the tug available in April 1978;
5. establishment of margin planning (time-scale, cost, performance);
6. trade-off investigations on the following subjects:
   - ground-based or space-based;
   - manned or unmanned;
   - newly developed tug or existing stages (Agena, Centaur).