FLORENTIN SMARANDACHE

A Generalization of a Theorem of Carnot

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Theorem of Carnot: Let M be a point on the diagonal AC of an arbitrary quadrilateral $ABCD$. Through M one draws a line which intersects AB in α and BC in β. Let us draw another line, which intersects CD in γ and AD in δ. Then one has:

$$\frac{A\alpha}{B\alpha}\cdot\frac{B\beta}{C\beta}\cdot\frac{C\gamma}{D\gamma}\cdot\frac{D\delta}{A\delta}=1.$$

Generalization: Let $A_1...A_n$ be a polygon. On a diagonal A_1A_k of this polygon one takes a point M through which one draws a line d_1 which intersects the lines $A_1A_2, A_2A_3, ..., A_{k-1}A_k$ respectively in the points $P_1, P_2, ..., P_{k-1}$ and another line d_2 intersects the other lines $A_kA_{k+1},, ..., A_{n-1}A_n, A_nA_1$ respectively in the points $P_k, ..., P_{n-1}, P_n$. Then one has:

$$\prod_{i=1}^{n}\frac{A_iP_i}{A_{\varphi(i)}P_i}=1,$$

where φ is the circular permutation

$$\begin{pmatrix}1 & 2 & ... & n-1 & n\\ 2 & 3 & ... & n & 1\end{pmatrix}.$$

Proof:

Let us have $1\le j\le k-1$. One easily shows that:

$$\frac{A_jP_j}{A_{j+1}P_j}=\frac{D(A_j,d_1)}{D(A_{j+1},d_1)}$$

where $D(A,d)$ represents the distance from the point A to the line d, since the triangles $P_jA_jA_j^{'}$ and $P_jA_{j+1}A_{j+1}^{'}$ are similar. (One notes with $A_j^{'}$ and $A_{j+1}^{'}$ the projections of the points A_j and A_{j+1} on the line d_1).

It results from it that:

$$\frac{A_1P_1}{A_2P_1}\cdot\frac{A_2P_2}{A_3P_2}\cdots\frac{A_{k-1}P_{k-1}}{A_kP_{k-1}}=\frac{D(A_1,d_1)}{D(A_2,d_1)}\cdot\frac{D(A_2,d_1)}{D(A_3,d_1)}\cdots\frac{D(A_{k-1},d_1)}{D(A_k,d_1)}=\frac{D(A_1,d_1)}{D(A_k,d_1)}$$

In a similar way, for $k\le h\le n$ one has:

$$\frac{A_hP_h}{A_{\varphi(h)}P_h}=\frac{D(A_h,d_2)}{D(A_{\varphi(h)},d_2)}$$

and

$$\prod_{h=k}^{n}\frac{A_hP_h}{A_{\varphi(h)}P_h}=\frac{D(A_k,d_2)}{D(A_1,d_2)}$$

The product of the theorem is equal to:

$$\frac{D(A_1,d_1)}{D(A_k,d_1)}\cdot\frac{D(A_k,d_2)}{D(A_1,d_2)},$$

but

$$\frac{D(A_1,d_1)}{D(A_k,d_1)}=\frac{A_1M}{A_kM}$$

since the triangles $MA_1A_1^{'}$ and $MA_kA_k^{'}$ are similar. In the same way, because the triangles $MA_1A_1^{''}$ and $MA_kA_k^{''}$ are similar (one notes with $A_1^{''}$ and $A_k^{''}$ the respective projections of A_1 and A_k on the line d_2), one has:

$$\frac{D(A_k,d_2)}{D(A_1,d_2)}=\frac{A_kM}{A_1M}.$$

The product from the statement is therefore equal to 1.

Remark: If one replaces n by 4 in this theorem, one finds the theorem of Carnot.